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BULLETIN NO. 127

A STUDY OF THE FACTORS INFLUENCING THE IMPROVEMENT OF THE POTATO

By EDWARD M. EAST



URBANA, ILLINOIS, AUGUST, 1908

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A STUDY OF THE FACTORS INFLUENCING THE IMPROVEMENT OF THE POTATO*

BY EDWARD M. EAST.

INTRODUCTION

Either because it possesses no strong flavor to dull the appetite, or possibly on account of its antiscorbutic properties, the common potato *Solanum tuberosum* L., has overcome seemingly insurmountable obstacles in its claim upon the public taste and has become a close rival to our cereal staff of life. The high cost of production and general uncertainty of the return, combined with the cost of transportation of a perishable, bulky product, would seem to be adverse factors which might preclude any general increase in growing the crop. Such has not been the case, however, and the potato, like other crops, has increased greatly in acreage in localities best suited to it, notably the sandy soils of the northern states. These soils seem to be so pre-eminently fitted for its growth that the crops are highly profitable even after deducting the cost of shipping long distances. During the last ten years,** the six states of Maine, New York, Pennsylvania, Michigan, Wisconsin and Iowa have furnished an average of one-half of the total crop of the United States. In other sections of the country where the growing of large crops is more unlikely from natural reasons, as inhospitable soil or climate, the cost of production has been high, and over-production at times (as in 1895-6) has had a very disastrous effect upon the price, occasioning great loss to the producer. This state of affairs is in a great measure due to the fact that in these sections the acreage per grower is small, and the business is not sufficiently organized to make possible long distance shipping, which would partially overcome the great local fluctuation in price.

The annual consumption of potatoes per capita in the United States for a period of thirty years is given by the Twelfth Census as three and one-half bushels, and when the amount available for human consumption is smaller than this,—as has been the case in the last few years,—the price precludes their use for other purposes.

*Submitted to the Faculty of the Graduate School of the University of Illinois in partial fulfillment of the requirements for the degree of Doctor of Philosophy, March, 1907.

**U. S. Dept. of Agri. Yearbook, 1905.

This has left capital invested in starch mills completely unproductive, as the limiting price within which the manufacturer can compete is forty cents per barrel of two and one-half bushels. There is no doubt but that the repeal of the tax upon alcohol for industrial purposes will furnish a channel for the utilization of all future excess of production over that used for human consumption, should the manufacturers of starch, glucose, dextrin and desiccated product,—who can pay a slightly higher price,—be unable to utilize it. At the present rate of increase of our population, however, the annual increase of production for human food alone must be from 3,000,000 to 5,000,000 bushels; and an increase, which would be a factor in the production of alcohol at all comparable with that of Germany, would have to be many times that amount.

The broad problems which confront the grower who has to face these demands, are, increased yields per acre and the development of varieties adapted to specific purposes. In the first instance suitable soil, available plant food, and proper methods of tillage and of combating disease will do much; but here as well as in the second case, probably the possibility for as great an advance lies in the province of the plant breeder.

The matter of variety efficiency to produce tubers in large quantities may be regarded as a desired accompaniment to all strains, no matter what other particular characters they may possess. The special characters, with the possession of which new varieties should be originated, are (1) an increase in nutritive value, (2) an improvement in table quality, and (3) a higher starch content. Coupled with the possession of each of these qualities should be the very important character of resistance to disease.

Since the potato is one of the world's cheapest food sources, if there is a possibility of finally obtaining varieties, which, without being perfect foods, yet would furnish a more nearly proper ratio of protein and carbohydrates; it would be an inestimable boon to the world's poor, for protein is a much more expensive food constituent than starch. This problem is inseparably linked with improvement in general table quality, for quality must in some manner be correlated with composition. On the other hand, varieties should be originated which yield a large amount of starch per acre, for the use of those growing for the starch, glucose or alcohol manufacturer. It is recognized that at the present price of production, maize is a much cheaper source of alcohol than potatoes; but with the American taste for high starch potatoes, such potatoes would be used as food except in times of over production, until

cheaper methods of production and better varieties make the potato a competitor with the cereals for manufacturing purposes.

This study deals with such questions as have naturally arisen in trying to form a basis for practical work in potato improvement; and includes an examination of the literature bearing upon the possibilities of attaining this end. The principles underlying practical work in potato improvement are very broad,—much too broad to be adequately discussed in a single paper,—and yet it seems impossible to separate them into narrow lines without ignoring principles which are essential to the work. For this reason it has been thought best to consider briefly such of these as are indispensable, without regard as to whether in every case they have been touched in the experimental work. No attempt has been made to discuss historical, agricultural or economic data, however, except in so far as such subjects relate to the improvement of the potato in desirable hereditary qualities. A considerable amount of literature has made its appearance since the beginning of the experimental work in 1901; but we have endeavored to give a resumé of the present status of knowledge of the subjects.

The writer desires to express his obligation to the Directors of the Illinois and Connecticut Agricultural Experiment Stations, E. Davenport and E. H. Jenkins, through whom was made possible the use of laboratory and other facilities of these stations; and who have given much helpful advice. Especial acknowledgment is made to Dr. C. G. Hopkins under whose direction the study was undertaken, and who has been a constant source of advice and encouragement.

I. THE USE OF OTHER SPECIES

The plant which bears the tuber which we call the potato, and which name has been extended to the whole plant, has a recorded history of only three hundred years, it having been introduced into Europe about the end of the sixteenth century. Its botanical character caused it to be called *Solanum tuberosum* by Gaspard Bauhin (86) in his *Phytopinax*, printed at Bâle in 1596. This name was followed by Linnaeus when binomial nomenclature was introduced.

There are several other members of the genus which bear tubers, but none has yet become of commercial importance. About twenty tuber-bearing kinds of *Solanum* have been at different times classed as separate species. J. G. Baker (6) has given us probably our best classification, after having made a thorough examination of all species at Kew, the British Museum, and the Lindley Herbarium, as well as many growing specimens. He concludes that there are only six distinct species: *S. tuberosum* Linn., *S. Maglia* Schlecht., *S. Commersonii* Dun., *S. cardiophyllum* Lind., *S. Jamesii* Torr. and *S. oxycarpum* Schiede. Later, (7) he places *S. Maglia* as a variety of *S. tuberosum* which reduces the number of species to five.

Solanum Commersonii Dun. has been shown by Labergerie (65) to be in all probability the most promising of the other species, in its commercial possibilities. In his extended investigations, it showed a great tendency to produce bud variations in color which were permanent, and which when propagated showed great differences in the production of tubers, immunity to disease, etc. A violet variation showed absolute immunity to late blight *Phytophthora infestans* (Mont.) De By., for three years, while plants of *S. tuberosum* growing near were stricken. The yield was as high as 100,000 K. per hectare with a composition much the same as the common potato. Rev. J. R. Lawrence of North Middleboro, Massachusetts, has recently stated, however, that his plants have not been immune to late blight.

S. Maglia Schlecht. of Chili, *S. immite* Dun. of Peru, and *S. verrucosum* Schlecht. of Mexico, have all been mentioned as species and varieties especially worthy of being tried in the hopes of finding strains which by selection might become of commercial value and be immune to certain diseases, or with which the same end might be reached by hybridization with *S. tuberosum*. No valuable commercial strains from these sources, however, have yet been produced.

Stuart (92) found in 1904 that *S. Commersonii* and *S. poly-*

adenium were quite resistant to late blight, while *S. stoloniferum* was not. In his later (93) report of 1905, they all showed a high percentage of infection. None of these species or varieties gave marketable tubers in his tests, but they had hardly been cultivated by him long enough to have become adapted to Vermont conditions. De Candolle (22 p. 49) mentions that *S. verrucosum* is not disease resistant.

It seems unlikely from past results, that there will be any great progress made through straight selections of other species, if we except *S. Commersonii*. This species has been thus far very unsatisfactory in the United States, but there is in it still cause for experiment. It is very variable in its habits of growth, length of stolons, shape of tubers and other important characters; hence there may in time be some promising strains isolated. Until we have such strains established, there will probably be little good from hybridizing mediocre elementary species with the common potato, for the hybridization is effected with difficulty.

For two seasons the writer has had under observation some plants grown from tubers of Labergerie's stock imported by J. J. H. Gregory and son, Marblehead, Massachusetts. *Phytophthora infestans* has not been troublesome during either of these seasons; hence, no data have been obtained regarding the comparative resistance of the plants to the fungus. I am compelled to state, however, that in no character of leaf, stem, flower or tuber, is the plant different from common purple tubered varieties of *S. tuberosum*. Either there has been some mistake in Labergerie's seemingly careful work, and there has been a mixture with tubers of *S. tuberosum*; or we must conclude that there have been bud mutations in at least five or six characters of *S. Commersonii*, giving a plant indistinguishable from *S. tuberosum*. The truth of the latter conclusion would give us a unique phenomenon that is of extreme importance to science, and the case must be confirmed before it is accepted as a fact.

Our plants have flowered freely, but viable pollen has been produced in extremely small quantities. Numerous attempts at hybridizing with *S. tuberosum* have all failed.

2. THE ORIGINAL PLANT

ORIGINAL HABITAT

A. De Candolle (22 p. 46) states that *Solanum tuberosum* was unknown to the aborigines of eastern South America, although *S. Commersonii* was common as a wild plant. Along the western coast, however, the potato was well known and its cultivation diffused from Chili to New Grenada.

Pedro Cieça de León (86 p. 5) in his "Spanish Chronicles of Peru," makes the first written mention of the potato in 1550.

"In the neighborhood of Quito," he says, "the inhabitants have besides maize, two other plants which serve as a great portion of their food, papas and quinúa. The papas has roots enlarged into tubercles, which are covered with a more or less hard skin; these when cooked have a pulp nearly as tender as a purée of chestnuts. When dried in the sun to preserve them, they are called chumo, and are thus preserved for future use. The fruit produces a stalk similar to the poppy. The quinúa is a plant about the height of a man and has leaves like the blite of Mauritania, and a small seed either red or white in color, from which is prepared a drink, and a food comparable to our rice."

Lopez de Gomara (86 p. 5) in his "Histoire générale des Indes" (1154) and Augustin de Zarate in his "Histoire de la Découverte et de la Conquête du Pérou" (1555) also speak of this "papas" which is still the Indian name of the potato. Jérôme Cardan in his curious work entitled "De Rerum Varietate" (Bâle 1557) expresses himself in these terms on the same subject:

"On the height of the mountains in the country of Peru, the papas are like a species of truffle which is served in place of bread, and are also dried in the sun. It is thus nature has wisely provided for all needs. When they are dried they are called ciuno. Certain people have found means to enrich themselves by transporting this commodity into Potosi. It is said that the root has a stem similar to that of Argemone. The papas have the form of chestnuts but have a more agreeable taste. They are eaten cooked or better as I said made into flour. They are found as commonly among other tribes of this peninsular as they are among the inhabitants of the province of Quito."

Other writers through the latter half of the sixteenth century, and travelers and writers later, (22) show conclusively that the potato was and still is wild in Chili, but that the probability is that the plants found seemingly wild in Peru, were either escaped from cultivation or were allied species for which it had been mistaken.

INTRODUCTION TO CULTIVATION

The Spanish conquerers of Peru introduced the potato into Spain and Portugal sometime between 1535, the date of the con-



FIG. 1. THE FIRST POTATO INTRODUCED INTO EUROPE. FROM CLUSIUS' WATER-COLOR OF 1588. (AFTER E. ROZE.)

quest, and 1585, whence the cultivation spread into Italy sometime early in the seventeenth century. From here, the potato in all probability went to Austria, from Austria to Germany, Germany to Switzerland, and from Switzerland to France.

Spanish voyagers also probably introduced the tubers to the English settlers in Virginia; at any rate they were being cultivated there before 1585, and were sent to England at the time of Sir Walter Raleigh's voyages to Virginia though not by Raleigh himself. From England, potato cultivation spread very rapidly to Ireland which needed a cheap food crop, and by the beginning of the eighteenth century, it had become one of its staples. Their universal use on the island from this time forward brought them their common name of the Irish potato. This nickname is not to be wondered at for Ireland still leads in the use of potatoes with an annual per capita consumption of twenty-five bushels, or seven times that of the United States.*

TWO VARIETIES INTRODUCED

We have seen that Bauhin wrote the first description of the potato in 1596, but as he in all probability received his specimen from Clusius, to the latter should be given the credit of the description of the first cultivated potatoes. The specimens described by Clusius were sent to him in 1588 by Philippe Sivry, Seigneur of Waldheim and Governor of Mons, who had received them from Italy at the hands of the Papal Legate. The accompanying plate of Clusius is from Roze's colored plate made from the original and has not been available before in an English publication. Speaking of his reproduction Roze says:

"This colored plate is a faithful reproduction from the most ancient document we possess on the introduction of the potato into Europe. For the original water-color which dates 1589 is kept with other writings and books of this epoch (of which the authenticity is certain) in the archives of the ancient sixteenth century printings and preserved in its original state at Anvers, Belgium, at the Musée Plantin-Moretus. The writing on the Latin manuscript which has also been reproduced from the original water-color is thus 'taratoufli à Philippo de Sivry acceptum Viennae 26 Januarii 1588. Papas Perüanum Petri Cieçae,' and is a fac-simile of the writing of the celebrated botanist Charles de L'Ecluse of Arras, more commonly known to the world under his Latin name Clusius.

"This proves to be, not the date of the reception of the water-color, representing a flower stalk with two potatoes which had only been sent to Charles L'Ecluse in 1589 by Philip de Sivry, Seigneur de Walhain et Gouverneur de la Ville Mons en Hainaut, but that of two tubers and one fruit berry of the

*Mayo-Smith: Statistics and economics, p. 38.

potato that Carrolus Clusius Atrebatius, in his *Rariorum Plantarum Historia* published by Moretus in 1601, declared to have been sent to him by Philippe de Sivry à Vienne at the beginning of the year 1888. These two tubers and the seeds from this fruit have produced all the potatoes which at the end of the sixteenth century were cultivated in Austria, Germany, Switzerland and France."

Judging from this plate and from what Clusius says in his "*Rariorum plantarum historia*" (17), the plant has changed little under cultivation except probably to give fewer and larger tubers. The larger tuber shown in the figure is one and three-fourths inches long and would weigh about 35 grams. He states in his work that the plant then yielded as many as fifty tubers of unequal size and from one to two inches long. This would still be considered a good yield for a two-year seedling and is commonly not exceeded here the first or second year by unacclimated varieties imported from Europe.

The other European introduction,—that into Great Britain,—was first described by John Gerard in his "*Herbal*," published in London in 1597. This has usually been given as the first description of the potato and the accompanying figure is a reproduction of his wood-cut as given in the edition of 1636. Gerard, however, knew of Clusius' description as is shown in the following quotation. He says, speaking of the potato:

"It groweth naturally in America, where it was first discovered as reporteth Clusius, since which time I have received roots hercof from Virginia otherwise called Norembega, which grow and prosper in my garden as in their own native country."

It is remarkable that these two introductions into Europe were made with two different varieties of *S. tuberosum*. The one described by Clusius which probably produced the earlier varieties of northern Europe, had reddish tubers and light purple blossoms. The later introduction into England described by Gerard possessed light brown to yellowish tubers and violet to almost white flowers.

The variations in the descendents of these two varieties have been almost entirely restricted to the tubers. The ash-leaved varieties of England constitute an exception, where the variation is in the shape of the leaf. This fact is important from two points of view. *First, it indicates that there has been but little correlated variation between underground and aerial parts, and hence we are unlikely to find plant characters by which we can with reasonable certainty reject unsuitable types. Second, with so little visible variation in the plant, there is likely to be narrow variability in resistance to fungus diseases, should such resistance be due to structural differences.*

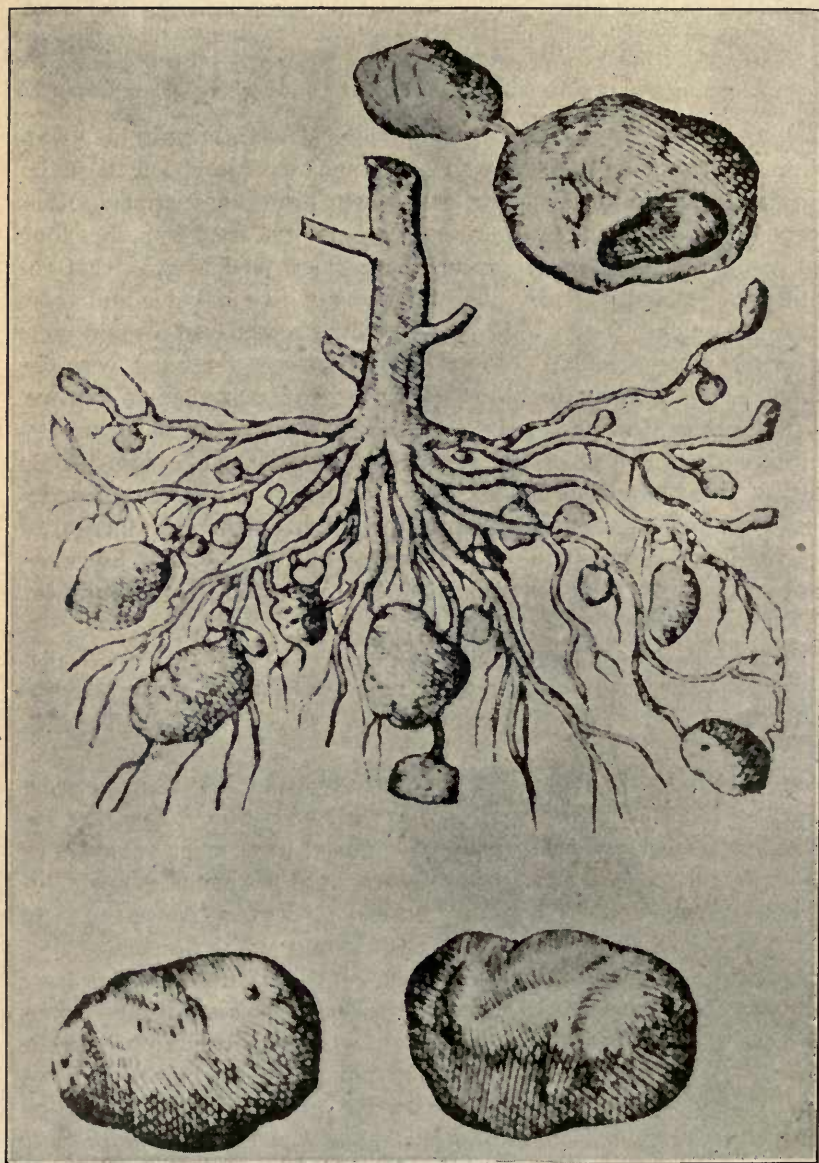


FIG. 2. THE FIRST POTATO INTRODUCED INTO ENGLAND. (FROM WOODCUT IN GERARD'S HERBAL. ED. OF 1636.)

3. THE MODERN PLANT

STRUCTURE AND CHARACTERISTICS

The potato is an annual, and in its original state reproduced freely by seeds. The tubers were then so small that it is doubtful whether the plant would have been preserved to us by this alternate means of reproduction. At present, however, many varieties never or at most rarely seed, and the plant has become virtually a perennial through its tubers.

Baker (6) gives the following technical description of a wild plant:

"Leaves pseudo-stipulate, a fully developed one about half a foot long, with seven to nine finely pilose, oblong-acute, large leaflets, the side ones stalked and unequally cordate at the base, the one to two lowest pairs much dwarfed, leaving a naked petiole about an inch long; the rhacis furnished with numerous small leaflets interspaced between those of full size. The flowers arranged in compound terminal cymes, with long peduncles; pedicels hairy, articulated about the middle. Calyx hairy, one-fourth to one-third inch long, teeth deltoid-cuspidate, as long as, or a little longer than, the campanulate tube. Corolla dark lilac, subrotate, nearly an inch in diameter, pilose externally; segments deltoid, half as long as the tube. Anthers bright orange-yellow, linear-oblong, nearly one-fourth inch long, filaments very short. Berry perfectly globose, smooth, under an inch in diameter."

This description perfectly fits the cultivated potato of today, as Baker has already noted, with the exception that the lobes of the calyx are now a little more pointed.

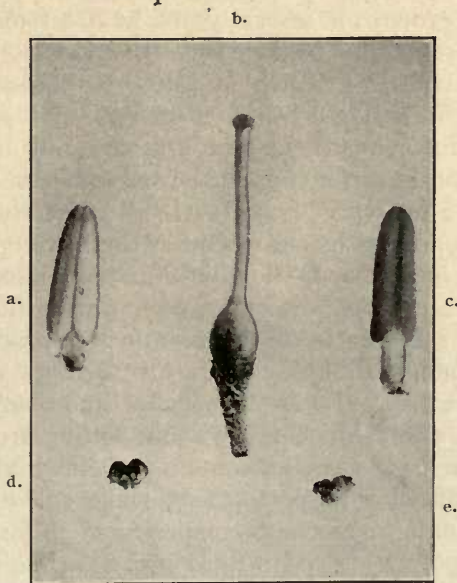


FIG. 3. PARTS OF POTATO FLOWER.

a. Back side of anther.
b. Pistil.

c. Front side of anther.
d. Cross section of anther.
e. Tops of anther showing the openings.

The flowers in the cultivated plants vary in color from white to purple, and usually two clusters growing side by side make up the compound cyme. They possess an entire, five pointed corolla with five stamens with large fleshy anthers enclosing the pistil. Darwin quotes Makenzie (68) as describing a variety which produced two sorts of flowers, the one double and sterile and the other single and fertile. The sexes mature at the same time; the anthers open at the top like a small cup, and in certain cases split for a short distance. The pollen is usually wind carried, as the flowers produce no nectar and are not greatly frequented by insects. Müller (75 p. 425) and Fruwirth (43 v. 3 p. 6) each mention several species, however, that they had noted around the flowers. Darwin considered self-fertilization possible; and from the comparative ease with which I have obtained "selfed" fruits in twenty-six different varieties, and from the rarity of insect visitors, I believe self-fertilization to be natural to the species. The flowers open between five and six o'clock a. m. in this climate and slightly close about dusk. The pollen is usually shed on the second day of blooming and it is then that the pistil is most receptive. With profuse seedling varieties the flowers wither about the fourth day.

Fraser (37 p. 5) states that out of three hundred varieties many of which he has grown for several years, he has found none which do not bloom at some time of their life. In opposition to this view, Rev. J. R. Lawrence, of North Middleboro, Massachusetts, who grows some eight hundred varieties asserts that some varieties never bloom. However this may be it is certainly true that there is a great variation in varieties in the power to bloom and still more in their ability to set seed. Some varieties evidently go for years without blooming, others bloom whenever there are optimum conditions of climate and season. I have found varieties setting seed freely in Waupaca county, Wisconsin, when during the same season plants from the same fields of the year before produced no seed in Champaign county, Illinois. There are varieties which develop clusters of buds which fall without opening, and many more which produce flowers, all of which fall without setting fruit. Some of the anthers in the latter varieties contain no pollen, others shriveled pollen grains containing no protoplasm, while still others produce viable pollen though never (in my experience) in large quantities. The blossoms separate at certain fixed places on the stem where a ring is formed by layers of tissue drying. Liebscher (66) states that fragrance is correlated with yield of pollen but I have found no noticeable fragrance in American varieties.

It is a common idea that the potato does not set fruit as freely now as formerly, and the explanation has been given that the production of large quantities of tubers has led to the degeneration of the seeding power. It is true that many of our finest varieties bloom seldom and rarely set seed, yet this does not seem to be a correlation with yielding power, for *some* of our best varieties bloom freely, and under proper conditions, set seed.

Fraser (37) has shown this variation in blooming to have been natural nearly two hundred years ago. He says:

"Mark Catesby, who was in this country in 1722-1726, wrote that 'in Virginia and to the north thereof, they (potatoes)' are annuals, and produce no flowers, while in Carolina and the Bahama Islands, they produce flowers. Many varieties existed at that time particularly in Virginia, and five kinds were common: the Common, Bermudas, Brimstone, Carrot and Claret potatoes. The Bermuda potato was the only one that had a white flower, the flowers of all the other kinds being purple. This was the only variety that had a white skin and was white fleshed. It was round in shape, more tender, and more delicate to raise than the others, and did not keep so well."

In Connecticut, many excellent varieties do not seed and cannot be used as stock to breed from, but varieties representing all of our favored commercial variations in shape and color, can be obtained which produce seed. In other climates, notably Maine, Minnesota and Wisconsin many of the non-seeding varieties of Connecticut produce pollen and seed comparatively freely. This makes it possible to obtain hybrid seed from varieties where the female parent at least is acclimated and adapted to these soils, for the female organs appear to be always perfectly normal.

The tuber of the potato is a swollen, underground stem, with its eyes equivalent to the leaf buds of an aerial stem, and which are arranged more or less spirally in each case. The main underground stem of the plant varies in length with the depth of planting. At intervals on this underground stem, stolons are sent out, at the extremities of which are found the tubers. Varieties differ greatly in the length of these stems and the manner in which the tubers are formed. A variety to be of commercial value should have very short stolons and bear only one tuber at the end. There should be no branches from the bud end of the tuber, as is sometimes the case.

The physiology of tuber formations is discussed at length by Vöchting (101).

VARIETIES OF TODAY

At present, there are in the United States over one thousand named varieties. This large list contains many names that repre-

sent potato plants and tubers having the same characteristics, and which are indistinguishable, even to an expert potato buyer. In some cases this has been due to the actual stealing of meritorious varieties by unscrupulous dealers, who have put out the stock under a different name, and given it a foothold by persistent advertising. More often, however, the duplication has been done by potato fanciers who are growing seedlings from naturally pollenized seed, and who obtain similar strains which are saleable to seedsmen, as new varieties for the single reason that *they have been obtained from seed*. If the yield is fair, and the tuber is of a popular type, the restless fancy of the American public for something new, gives a ready, though temporary market for the stock from the new seedling no matter if it is slightly inferior to its already established prototype. I have seen at least twenty named varieties of the Carman No. 3 type (short-oval-flat with white skin) which were absolutely indistinguishable in shape, color, and manner of growth, and if the popularity of this type continues there will undoubtedly be an annual addition to this list of names.

Of real variations in varieties, productive efficiency or ability to excel in crop production under like conditions of environment, is the character of greatest importance at present to the grower. The astonishing adaptability of some varieties as compared to others, to certain soils and climates is shown in the following table from varieties grown at the Connecticut Agricultural Experiment Station in 1906, on plots of poor but uniform soil with like treatment as to planting, cultivation, fertilizers, etc. To what these differences are due: whether there are many different elementary species in *S. tuberosum* whose characters have been recombined into innumerable varieties by hybridization; or whether they are due merely to desirable fluctuations that regress slowly because of bud propagation is unknown. The fact of the differences remains.

TABLE I. VARIATION OF VARIETIES IN PRODUCTIVENESS UNDER UNIFORM FIELD CONDITIONS

Variety.	Yield per acre in bushels.	
	Marketable.	Seconds.
E. Six Weeks.....	18.7	8.2
E. Ohio.....	36.2	11.7
E. Norther.....	57.2	30.3
Minister.....	74.7	23.6
E. Manistee.....	79.3	14.0
Twentieth Century.....	102.7	11.7
State of Maine.....	113.2	17.5
Green Mountain.....	137.7	18.7

Owing to the great local differences in soil fertility and physical character, this character of productiveness must be determined by trial in every climate and for every soil. It is pre-eminently the desired character of the grower, as all other characters are at present, more or less fancy demands of the consumer, and concern the grower only so far as the urgency of the demand affects the price. Some of the characters that generally receive attention from modern growers as conducive to, or correlative with, yield,—are disease resistance, character of haulm and leaf, time of maturity, and length of stolons.

The first character is well discussed in a recent publication of Jones (59). In the writer's experience there is certainly a variation in the ability of different varieties to resist attacks of early and late blight, but whether the differences noticed *within* the variety are due to anything but a different time of infection is questionable. That there are wide individual variations in respect to susceptibility toward the physiological trouble, tip burn, is more apparent.

The haulm should be vigorous, covering the ground when in full growth, but upright and bushy rather than long and sprawling. The meeting of the plants in the row conserves the soil moisture when cultivation can no longer be given while an upright, bushy haulm favors ease in the farm operations, and probably tends to lessen disease infection.

In general, varieties yield in proportion to their growing season, provided there is entire maturity before frost. Varieties which are still green at the close of the season have large numbers of tubers set but a great many of these fail to reach a marketable size and the plant is killed while still containing much dry matter which should have been transferred to the tubers. Length of stolon seems to be a very strong variety characteristic and permanent when obtained. The length should never exceed three or four inches, although with *S. Commersonii*, it sometimes reaches the extreme length of ten feet.

Variety characteristics which are prominent and which depend almost entirely on the public taste to be of value, are those of tuber shape and skin character. There are varieties possessing every possible shape, but they may be roughly divided into the oval and the round and, if we wish to make a third class, the kidney shaped. The popular shapes at present are quite flat, the short-oval-flat being the most desired. There may be a sufficient reason for this, as Fischer (32 v. 2 p. 49) found that flat-round tubers or flat-oval tubers showed a correlation with starch content. The actual reason for popularity would seem to be the fact that potatoes of this shape give a greater weight per measure, in which manner they are usually retailed. The eyes of potatoes of this type are also comparatively shallow, thereby giving less waste.

Skin color seems to be purely a matter of preference without a real reason, there having been no correlations shown between particular colors and other desirable qualities. White to light brown are the colors most sought in the northern markets while red skinned varieties find ready sale in the south. Krzymowski (63) states that rough skinned varieties are highest in starch content; and it is generally believed that this is also correlated with resistance to scab.

MODERN POTATO BREEDERS

Growing potato seedlings has been a fascinating work for thousands of gardeners throughout the United States, who have taken up the work merely as a recreation and have planted seeds of unknown parentage, rejecting year by year those which gave poor yields or had characteristics which were thought undesirable for market. The mere fact of numbers has brought from this desultory work a large number of commercial varieties, a conspicuous example being the Burbank potato. This variety was the progeny of a natural seed ball found in a garden by Mr. Luther Burbank when he was a boy. As we only hear in such cases from those who are successful, there is no way of judging the percentage of failures; but judging from those who have come to my personal knowledge, and from talking with seed merchants, certainly not over one or two percent of these growers ever produce a commercial variety. Varieties which come into prominence today show increasing evidence of the work of the breeder who studies his ground carefully and works toward a definite end. It is probably not too much to say that 90 percent of our present potato crop is from varieties originated by scientific breeders, such as the late E. S. Carman. The small amount of published matter concerning the present day workers in potato breeding and their methods makes correspondence necessary for organized work, and a list of some of the prominent workers is given here.

United States: O. H. Alexander, Charlotte, Vt.; Marvin Bovee, Northville, Mich.; E. L. Coy, West Hebron, N. Y.; W. E. Johnson, Bowdoinham, Me.; J. R. Lawrence, E. Raynham, Mass.; Chas. Norcross, Litchfield, Me.; C. S. Pringle, Charlotte, Vt.; Hiram Presley, Port Huron, Mich.; E. L. Roser, Cleveland, O.

Great Britain: James Clark, Christ Church, Hants; Robert Fenn, Holmwood, Sulhampstead, Reading; C. Fidler, Reading; A. Findlay, Markinch; T. A. Scarlett, Edinburgh; A. W. Sutton & Son, Reading.

France: Tibulle Collot, Maizières; Forgeot & Cie., Paris; Léonard Lille, Lyon; Hyacinthe Rigault, Groslay; Joseph Rigault, Groslay; Vilmorin-Andrieux et Cie., Paris.

Germany: Cimbäl, Frömdorf bei Münsterberg; Flieszbach, Curow, Pommern; A. Kirsche, Pfiffelbach; von Lochow, Petkus; G. Rödel, Tagewerben bei Weizenfels.

4. METHODS OF BREEDING

GENERAL BASIS

In potato breeding, there are four steps before the worker: 1. Selection of varieties for improvement. 2. Discovery of valuable bud-variations. 3. Selections of mother plants, and their crossing. 4. Comparison and selection of the progeny. It is the province of the breeder to discover the best methods for prosecuting this work, —the obstacles in the way, and the probabilities of success under different conditions. The means of propagation of the potato is in most of these steps a disadvantage. The comparatively simple methods of the seed propagated annuals and biennials are seriously complicated, and the advantage of grafting held forth by the orchard fruits is lacking.

In taking the first step, it is in some cases impossible to select varieties with characters that are desirable, to combine with those possessing other characters, because of the large number of varieties which produce no viable pollen. A great number of varieties must be grown, and the matter as to whether fertile pollen is produced in quantities large enough to make hand pollination practicable must be determined during their comparison as varieties. It has been held by many horticulturists since the time of T. A. Knight (60) that varieties which did not bloom readily could be stimulated into fruiting by removing the soil from the underground stems, or otherwise preventing the production of tubers. This does not seem to be true at present with American varieties, for with ten different varieties in Connecticut and with five in Illinois, we obtained by this method no natural seed balls, and by microscopical examination found no seeming increase in production of viable pollen. *At least, we might conclude that the reaction to this means is not certain enough to be of great value to the breeder, and seed producing varieties must be selected which come nearest to the ideal in the characters needed.* Some hybridists select parent varieties of similar type with the idea of improving qualities already obtained, while others cross widely divergent types, with the hope of obtaining a smaller percentage of seedlings with much better characteristics. Doubtless both methods are necessary, if it is certain in all cases that there are eminently desirable characters in the types used.

Having selected the varieties with which to work, it is of doubtful value to use any of the old-time horticultural methods,—such as over supply of food materials,—to induce variation. We may in the future learn to use artificial means to produce mutations, but the “plus” fluctuations induced by food supply are probably absolutely valueless when we are about to resort to sexual reproduction

in the origination of new types. But, even if artificially produced fluctuations were heritable, there would be no necessity for their production; for, owing to the hybrid character of the greater number of potato varieties—or for other reasons—the natural variation of seedlings is very great, even when they are the product of crosses within the variety. Foreign varieties may very properly be grown until they are fully acclimated; that is, until the varieties are growing with full vigor. During the first year or two such varieties seldom flower; and even if they do, the flowers fall more quickly than they do with vigorous plants, and hybridization is effected with difficulty.

There is also some doubt as to the value of bud variations, but pending further investigations, we should watch for any such occurrences. Data soon to be published by the writer seem to indicate that progressive mutations, that is, the appearance of an entirely new character, rarely and possibly never, occur. Bud variations are in nearly all cases merely the loss of a dominant character leaving the recessive allelomorph to appear. Such variations are not likely to be of great economic value.

The selection of individual plants to be crossed is still a matter of personal opinion and experiment. While we may not believe in the heritability of vigor occurring as a fluctuation within a variety; still the greater ease of making crosses between vigorous plants is a sufficient reason for their selection as mother plants. The latter is due to the greater probability of their retaining the seed ball to its maturity.

Girard selected plants having the most luxuriant vegetation, and according to T. A. Scarlett (88), the same method is practiced in Scotland. We have found that there is a great difference in varieties, as regards the value of luxuriant vegetation as a guide in selecting high yielding plants. Large vines versus medium vines gave fair results in most cases; but in some varieties as Manistee, large vines rather indicated that excessive vegetative growth was opposed to maximum tuber formation.

TABLE 2. SELECTION OF HIGH YIELDING PLANTS BY SIZE

Variety.	Average vine production in ounces.		No. counted of each.
	Large vines.	Medium vines.	
Pink Gem.....	21.5	14.25	50
Sir Walter Raleigh.....	24.1	19.3	50
Carman No. 3.....	22.1	20.0	10
Early Ohio.....	16.0	16.1	10
Early Manistee.....	16.6	16.9	10

There is no constant difference due to selection of plants with a single stem and those which branch just below and just above the ground, providing they are equal in top weight and that it is certain that the branched selections are single plants. There appears, however, to be an optimum shade of color in vines, constant with the variety, which is correlative with, or a result of vigor in the plant. Lighter colors gave fewer potatoes although these were of good size, while darker colors either gave no set of tubers or a large set of very small tubers. The latter condition sometimes seems to be due to a very late setting of tubers in late varieties, leaving too short a season for the tubers to mature.

The actual crossing of the plants selected is a simple matter. The corolla and stamens of the selected blossom of the mother plant should be cut away before it is fully developed, and the blossom then bagged with a small waxed paper bag. When the stigma is receptive (sticky), dust on the pollen collected from the "sire" plant with a camel's hair brush. This pollination should be repeated on two successive days, if the pistil has not fallen. It is better to limit the fruits of the mother plant to two, but several flowers should be pollinated in order to stimulate growth in the peduncle of the cyme. When the fruit has begun to form, remove the bag to allow free access to air and light. When the fruits are ripe, they are gathered and allowed to dry. It is better for their viability to squeeze out, clean and dry the seed, rather than allow them to stay all winter in the berries where there is an opportunity for decay.



FIG. 4. IRREGULAR CYME OF POTATO FLOWERS. ONE READY FOR POLLINATION.

The seed is planted in a hot house in February and transplanted twice before planting in the open after danger of frost is over. Fraser (37 p. 174) believes the old idea of this first year crop consisting of small tubers does not always hold and states that a tuber weighing over seven ounces has been grown the first year. He says, "The Burbank potato was full size the first year it was grown from seed, and many breeders feel that unless the tubers are of edible size the first year that they are not likely to be worth further care." Girard (45) also states that with proper cultivation, seedlings will produce marketable tubers in one or two years.

I have seldom seen a marketable tuber produced by even a two year seedling, and think that such results must be unusual. The vines certainly often reach full size the first year, but the growth is almost entirely vegetative with very little matter stored in the form of tubers. The vines producing the larger tubers seldom produce a large number, and I have been told by several reliable breeders that they prefer,—the first year as well as subsequent years,—to select the vines having the largest number of tubers. And while there are no comparative data, the use of the plant as a whole as a selective unit appears the more reasonable. The great majority of the seedlings produce tubers of only one to fifty grams weight the first year and require three years to reach their full size. It is also noticeable that the typical shape of the strain is not generally shown the first year, the tubers at this time generally being round in shape.

PRECAUTIONS IN COMPARATIVE TESTS

After the first year the elimination of the unfit begins. The tubers from the year before are compared in the garden in short rows and as elimination goes on the best are given field trials. In carrying out all field and garden comparison tests, there are a great number of factors which have an influence upon growth, and which, as far as possible, must be taken into account; for a field test at best has a large experimental error and the error with potatoes is probably larger than with any of the seed propagated annuals.

The more common operations of all field experiments which first come to mind and which scarcely would be neglected in the comparison, are absolute uniformity in the time of planting, number of times and methods of cultivation and spraying, kind and amount of fertilizer, and time of harvesting after dividing the varieties into early, medium and late maturing. There are a number of other points which have been neglected in far too many potato

investigations. A common error, as Thorne has pointed out (97), is in disregarding the type and topography of the soil. The soil should be as uniform as possible, preferably of sedentary origin, and previous to its experimental use, should have been fertilized and cropped in exactly the same manner. The land should be slightly rolling and the potato rows should run up and down the declivity so that the comparison of the whole rows is perfectly fair. Water is a very important factor in potato growing, and small depressions in flat lands receive an unequal portion of the surface drainage which vitiates the results.

E. Pagnoul (77) attributed the large yield of potatoes in seasons when the total hours of sunshine were large, to the effect of light on elaborating starch. His results may be slightly distorted as he reports only a portion of the conditions which enter into his experimental error, but results as reported gave a ratio of approximately 1:5:11 for plants under darkened glass, clear glass and open air respectively. Therefore precaution should be taken concerning all shade.

Results from numerous experiments, among the most accurate of which are those of Maw (74) and Plumb (82), have shown that much care must be taken to have equal weight of seed planted, for other conditions being equal, the yield of tubers increases directly with the weight of the seed piece although not exactly proportional.

Arthur (2, 3) and others have pointed out a difference in yield owing to the difference in age and vigor of eyes sprouted before planting. Wilting tubers up to a loss of moisture of 20 percent also increased growth. He advances the proposition that: "Whatever increases rate of growth at the beginning, increases yield." Finally Gilmore (44) has shown that depth of planting certainly affects the quality and on certain soils the yield; while Clinton (16) suggests that it may also cause a difference in time of infection with *Phytophthora infestans*.

These factors can probably never all be controlled in the same experiment but they should all be kept in mind, and all reasonable effort made to lessen errors due to them in comparative tests.

CORRELATIONS

Many so-called correlations of characters have been observed by different investigators. These correlations are said to be sometimes very marked, and of great value in making selection where one of the correlated characters is easier to select from than the other. The physiological reasons for many of these ef-

fects are obscure, and there appears to be no certain way of distinguishing between what might be called real correlations, which are probably to a greater or less degree effects from the same internal cause, or where two characters are inherited as a single unit: and false correlations in which one is the cause and the other the effect, or in which both characters vary as the result of some external stimulus. In practical work either type may become a help in its prosecution, but in studying problems of heredity, inability to distinguish the type often leads to great confusion. Space cannot be taken to comment upon these observations except to make the statement that it has been the writer's experience that the degree of correlation of any characters which he has observed, is extremely variable with different varieties, on diverse types of soil, and in dissimilar seasons.

With regard to the production of plants, Arthur (2) in an elaborate investigation found that the number of stalks is very slightly if at all related to the number of eyes upon the seed piece, provided pieces of equal weight are used. The number of stalks, however, increases directly with the weight of the seed piece; and with the number of stalks varies directly the number of tubers and their total weight in the produce. He also and later Wollny (112) state that the eyes of large tubers produce stems of a sturdier growth.

Liebscher (66) states that thin stemmed plants produce small tubers and that plants with fine stems produce many small tubers.

There seems to be no constant relationship between colors of tubers and of blossoms or between dark skinned tubers and dark vines, but Liebscher (66) found that profuse blossoming points to late ripening, and heavy seed setting to small tuber formation. The latter statement has been a general belief but Fraser (37) states that in his experience many of the heaviest yielding varieties at least bloom freely. Liebscher believed seed and tuber production to be physiologically opposed. Fruwirth (43 v. 3 p. 10) states that Dalkowsky is of the opinion that strong power of seed production is also correlated with ability to resist disease.

Osterspey (76) found in early varieties less foliage than in late varieties; and within a variety, in both early and late varieties, there was a relation between number of tubers and number of stalks.

Fischer (32) found that flat-round tubers were richer in starch and produced less massive plants; while long-cylindrical tubers were poorer in starch and produced large straggling foliage. Fru-

wirth (41), in three years' observations with both early and late varieties found a relation between yield and the following characters: Flat shape, number of stalks per plant, length of growing period, height of plants and number of tubers per plant. He also states that the greater the number of stalks from a plant, the thinner are the stalks.

Some of these correlations may help materially in eliminating some of the undesirable plants from the progeny of crosses from which we are trying to build up new varieties. There may also be many pairs of characters with high percentage correlation which have not yet been noticed but which will be brought out with further statistical studies. It is doubtful, however, if many of these characters which appear to be related in certain varieties, are to be regarded as *real correlations* characteristic of the species. Reasoning from statistical studies of the writer on maize and sugar beets, which may or may not be analogous, it would seem that correlations which are likely to be of most practical value in making selections will probably be found in very narrow blood lines (elementary species?). For example, in ear-to-the-row tests of dent maize there was planted an ear with a peculiarly shaped tip. This ear yielded very highly, and of its progeny when grown and their yield compared, in nearly every case, those were found to average highest whose mothers had this peculiar tip.

In hybridization, pairs of characters may be found which are inherited as a single character. When both characters are desirable, this would be a decided help, but when one character is undesirable, there is only the consolation of knowing the difficulty of finding exceptions to the rule. Johannsen (58) states however that, "Crossing is the means of breaking the correlation."

In selection, those correlations are of greatest value which allow us to eliminate plants through correlations of characters in the young vines, with characters in the tubers. It is doubtful, however, whether weak correlations should be used in originating varieties. They are probably of practical value only when the life history of the variety is known.

5. INHERITANCE OF CHARACTERS IN TUBER
SELECTION

THEORY

We do not mean by this term the inheritance of the characters in future sexual crosses, but the transmission of selected variations from year to year by tubers. A consideration of this question is of practical importance to the potato grower. The potato breeder may still continue to make crosses and originate varieties, but in such work he is and must be a specialist. His work can never be undertaken with profit by the average grower, to improve his stock. On the other hand, if there is a possibility of selecting and propagating favorable fluctuating variations and their accumulation for the betterment of the variety, such work can be undertaken with success and profit by the farmer.

It is common knowledge that during the first few years the progeny of a sexual cross in potatoes is quite variable. These variations may be arbitrarily divided into two classes: First, those variations that seem to be due directly to slight differences in environment, such as shape, size and yield of tubers, and vigor of growth and amount of foliage in plants; second, variations that are much rarer and that seem to be of a more nearly botanical character as those of color tubers, length of life of plant, and amount of blossoms and production of seed. Variations, in the after life of the variety are said to become less common, that is, the type of the variety is said to become fixed. This appears to be true from general observations of potato seedlings, and it might partially be explained by the fact that each year the plants are subject to rigid selection to a certain type. *If these fluctuations are transmitted*, the plants dealt with in subsequent years are a *selected and not a general race*. But when unselected it is probable that there is a lessening variability with advancing age, even when the physiological vigor of compared plants is kept the same. Vernon (99 p. 184) showed conclusively that for low forms of animals as the sea urchin that the "Permanent effect of environment on the growth of a developing organism diminishes rapidly and regularly from the time of impregnation onwards." A little later De Vries (26) enunciated practically the same law for plants. He concludes: 1. The younger the plant, the greater is the influence of external conditions on its variability. 2. The nutrition of the seed when developing on the mother plant has (at least very often) a greater influence on the variability than during germination and growth.

Hence if we consider a potato variety as a perennial individual, though divided, we may conclude that following these laws the variability lessens as the variety becomes older.

Admitting this law to be sufficient reason for lessened variation in the variety as it ages; there is still variation, and as Bailey (4) has shown considerable variation, both continuous and discontinuous, or with De Vriesian names, both fluctuations and mutations. In the progress of evolution, such variations must have been sufficient either as mutations or as accumulated fluctuations to have created varieties and even species. In no other way could the numerous species and varieties of the asexually propagated fungi have originated, as well as numerous varieties of higher plants of various families, as sugar cane, banana, weeping willow, sweet potato, olive, fig and date which seldom or never are propagated by seeds. But as most biologists now accept the doctrine of discontinuous evolution we cannot *a priori* conclude that partial fluctuations (using the terms described below) are inherited even in the temporary Galtonian way in which individual fluctuations are inherited. De Vries (27) divides fluctuations into two heads which he says "obey quite the same laws," but which with respect to questions of heredity should be carefully separated. "They are designated by the terms 'individual' and 'partial' fluctuation. Individual variability indicates the differences between individuals, while partial variability is limited to the deviations shown by the parts of one organism from the average stature." Fluctuations, he says, take place in only two directions, the increase or decrease of what characters are already available, and in this way are fundamentally different from mutations which take place in all directions, and if progressive produce new characters. He concludes that partial fluctuations are usually far smaller than individual and partial fluctuation together, and that partial variations do not appear to offer important material for selection.* Multiplication by buds, however, of high extremes of individual fluctuation, he says, is what the breeder desires to obtain.

From De Vries' work, we might conclude that although partial fluctuations obey the same laws as individual fluctuations, there is not a great chance for improvement through their selection, because of their narrowness. Theoretically the fluctuations of the whole of any variety of potatoes belong to this class. Still the variability

*De Vries, however, admits the possibility of the commercial value of the selection of partial variations, when he says (P. 766): "Potatoes for the factory have even been selected for their amount of starch, and in this case at least, fluctuating variability has played a very important part in the improvement of the race." This is an admission of something that cannot be regarded as an undisputed fact.—E. M. E.

should be greater in the potato than in parts of perennial plants from a single rootstock,—from the latter class of which De Vries obtained a great deal of his data,—on account of greater diversity of environmental forces. The variation here ought to be analogous to the individual fluctuations of the fungi, or asexual animals which have the power of obtaining food in different places and of being surrounded by diverse conditions.

A study of the actual amount of difference of fluctuating variability in asexual and sexual reproduction has been made by Pearson (80), who also makes use of Warren's (102) work on parthenogenetic reproduction in *Daphnia*. Their work makes use of data from both animals and plants which might be criticized as not being strictly comparable, although most great biological laws have thus far seemed to apply to both animals and plants.

His first proposition is that selecting one parent reduces the variability of the race by only about 5 percent while selecting both parents reduces it about 10 percent, and this is almost the limit of reduction even if the whole back ancestry be selected. The variation then taking place is, of course, from the new type and not from the unselected type.

This proposition if true for such reproduction* as there is in potatoes, would show the probable amount of reduction of variability which there is in the established variety after it has been selected to type for several years and then placed on the market, leaving out of consideration the lessened variation due to greater age in the variety.

The next point is that the individual† variability in a fluctuating character after a bi-sexual union is not greatly less than the variability of the race. As an example, is taken the number of stigmatic bands on the capsules of Shirley poppies. The racial variability is 1.885 bands, the individual variability based on 300 plants is $.8518 \times 1.885$, or a reduction of 15 percent. Again, the racial variability of the number of leaflets on the compound leaf of the ash was found by examining two hundred trees to be 1.976; the partial variability is $.9181 \times 1.976$ or a reduction of only 8 percent.* *

The last point is made on the variability of mothers and daughters in the purely asexual reproduction of *Daphnia*. The variability of the mothers for a certain character was 2.221, for their daugh-

*This fact should be true at least for selection from crosses.

†Pearson does not distinguish here as does De Vries between individual and partial fluctuations.

**The writer does not subscribe to all of Pearson's conclusions on homotypy. There are, however, certain fluctuating characters where the individual variation is probably but little less than that of the race.

ters 2.950; for the array of daughters due to a mother of given character, an average of 2.610. Even after considering that mothers are a selection and not a race, the following conclusions are drawn:

(1) "In asexual reproduction an individual does not produce a facsimile of itself, and the variability of its offspring is not immensely reduced below the variability of the race.

(2) The asexual individual has offspring exhibiting regression, just like the sexually reproductive individual. Its offspring tends to regress from the individual to the race type.

(3) With high probability but not definitely, the asexual individual represents the mid-parent (1), i. e. .466 and .619 are well within the probable errors of the values .424 and .600, which we have found (Grammar of science p. 471) for the correlation and regression of the mid-parent in the case of the biparental inheritance."

Summing up the whole case, he says:

(1) "Whatever be the physiological function of the sex in evolution, it is not the production of greater variability."

(Note) This does not mean that sex is not a great factor in producing a great variety of forms by combinations of existing diverse characters, but these differences must exist in the parents or previous ancestry of the individuals producing this combination.

(2) "The variability of the individual makes itself felt not only in the biparental reproduction but in autogamic and parthenogenetic reproduction, and further in the undifferentiated like parts of the same individual.

(3) Whatever amount of selection has taken place, there seems no possibility of reducing variability beyond some 10 percent or 11 percent."

From the evidence given above, it seems reasonable for us to make the following conclusions as a working basis for our own problems. First, that there is fluctuating variation in asexually propagated vegetation which when reduced to a basis comparable to sexually propagated plants, is not to a great degree inferior. Second, that decreasing variability in a potato variety need not be due to a fixation of type which presupposes an inheritance of fluctuations. It may be explained by the decreased reaction to environment of an aging individual. Third, that, if partial fluctuations obey the same laws as other fluctuations, types may be changed by their selection; and this selection reduces the variation of the character in the neighborhood of 10 percent.

Our whole problem is reduced to the question whether types may or may not be changed by the selection of fluctuations. If types may be changed by the selection of individual fluctuations, they may likewise be changed by the selection of partial fluctuations. Until recently an affirmative answer to this theorem would not have

been questioned. All of our conclusions, however, have been based upon the supposition that the data obtained in experiments with fluctuations, were obtained from homogeneous material. Johannsen's (58 a, b) work has thrown into considerable doubt the homogeneity of natural populations. He has, moreover, concluded that the selection of fluctuations has nothing to do with the improvement of a race. Probably no other conclusion of recent times is so important to plant breeders. The work should certainly be duplicated along as many lines as possible; for its corroboration would not only sound the death knell of methods of improvements by the selection of partial fluctuations, but would entirely change our conception of procedure in other breeding operations.

Johannsen's experiments were made upon typical fluctuating characters, such as weight and length of seeds. The plants used were species, like beans, that could be self-fertilized during successive generations. All of the descendants of a single plant, arising by self-fertilization, he speaks of as a "pure line." The members of a pure line were distributed normally around a modal or type value in the case of each character considered. Likewise, all seeds from plants of the same variety, made up of a large number of pure lines, showed a normal variability. Some of the modal values of the pure lines were very close to the modal value of the variety, while in other pure lines the modes were quite different from it. When any individual, differing widely from the mean value of its pure line, was selected for propagation, its offspring showed almost a complete regression to the type of its particular line; but showed no regression whatever to the type of the variety.

He concludes, then, that a natural variety consists of a larger or smaller number of distinct types, each type having a distinct modal value for particular fluctuating character. These distinct types he calls "biotypes." Only by mutation or some rearrangement of characters can a pure line come to contain more than one biotype. If such a phenomenon takes place, the new biotype can be isolated, and remains true until another mutation or rearrangement takes place. It is quite clear that the only rôle of selection is to more or less completely isolate the different biotypes of a variety.

Johannsen leaves out of consideration forms of vegetative propagation; though for what reason I cannot understand. Tuber reproductions in potatoes is a form of reproduction in a pure line. If these conclusions are wholly warranted,—and Johannsen's work is extremely careful,—*no improvement can be made by selecting plus fluctuations in potatoes, except upon the intervention of mutative*

changes. That mutative changes do take place, we are certain; but nothing is known of their character or frequency. I believe that potatoes are very good material with which to throw some light upon the subject. It is only just to note, however, that the experimental work reported in this paper was planned and executed before Johannsen reported his experiments. The experiment has now been revised to better fit the problem.

EXPERIMENTAL EVIDENCE

Believing that the practical experiments in tuber selection are of some value, we have made a study of the reported results.

As early as 1860 Hellriegel (55), from a three years' experiment, came to the conclusion that it is not possible to improve a variety of potatoes in starch content by the selection of tubers having a high specific gravity. His experiments gave the following starch contents from selections of tubers of high and low specific gravity:

	1858	1859	1860
From mothers of high specific gravity.	1.0789	1.0907	1.0720
“ “ “ low “ “	1.0776	1.0888	1.0701

It can be seen that the slight difference shown here might easily be due to experimental error and that there is no cumulative effect due to the selection.

Franz (36) in 1878 concluded that from his experience and from general farm practice that varieties at least could be kept up in vigor by the selection of the seed.

Emery (30) took a step in advance in method and used one hundred tubers from poorest hills as compared with one hundred tubers of the *same weight* from the best hills. His results were irregular and he came to no conclusion.

Wollny (110) took a further step toward lessening experimental error, and used only tubers of the same weight, but he concluded that selection of tubers with a high specific gravity shows no definite influence upon the progeny either in quality or amount of yield.

Later Marek (69) opposed these conclusions. His work is weak, however, from the fact that he divided his tubers into different sizes, and after finding that the heaviest tubers were highest in specific gravity, he used them as seed. The results were probably due in great measure to the heavier seed piece used.

Marek's work stimulated Wollny (113) to continue his investigations. In this later work his former conclusions were modified. He found that in the majority of cases the progeny of tubers having a high specific gravity were of a slightly higher specific gravity than those descended from tubers of a low specific gravity. He believes, however, that it is very doubtful whether any effectual improvement of the value or yield of a variety could take place through selection of tubers of high specific gravity. Further in Marek's* final report, he admits practically the same thing.

Girard (45, 46) reached the same conclusion with regard to specific gravity with the use of five varieties, but highly recommends the selection of high-yielding plants in the field as means of keeping up the yield of the variety.

Hebert found no transmission of high specific gravity with a large number of experiments with Richter's Emperor.

Wohltmann's (107) and Thiele's (96) results showed that the hereditary transmission of starch content had not been clearly proved.

Goff (49), in experiments begun in New York in 1884 and continued four seasons, found that the yield of tubers from productive hills was greater than that from unproductive hills, but that the difference in yield between different rows of selected tubers was often as great as the difference between the two selections, and even this might be entirely due to the fact that the plantings were all made from single eye pieces, which were larger in those from productive hills. Realizing the error in planting different weight seed pieces, he (50) began again in 1899. This time the same number of tubers and of cuttings were taken and the combined weights of each selection were made the same. The collected results were as follows:

Variety.	Old long Mercer.		Snowflake.	
	Productive hills.	Unproductive hills.	Productive hills.	Unproductive hills.
Total No. of tubers produced in 2 yrs.....	104	68	232	195
Total wt. in oz. produced in 2 yrs.....	64	41	332	100

*Marek, E., Deut. landw. Presse 1895:274.

He concludes that the vigor of the plant may be maintained and even increased by selection; but that the experiment has not tended to increase the yield of the varieties used, for the reason, he says, of the continued cutting of the best tubers.

Bolley (12) has for a number of years carried on an investigation concerning the use of large and small tubers from the same hill. Bud end pieces of equal weight, cut to one eye piece were used, and all details of the experiment very accurately controlled. From three years' observations, he concludes that: "In planting equal weight pieces from small and large tubers of the same vine, there will not be a sufficient difference in favor of the one or the other size of potatoes to be noticeable under farm methods, provided all are normally mature." This shows that selection of large potatoes from the bin will not necessarily do anything toward improving the crop. He concludes also from his general observations on his stock, that variations in forms, size, roughness of skin, malformations, number of tubers, etc., are produced to some extent though influenced greatly by seasonal conditions. From this he concludes that selecting from high yielding plants should improve the yield. Later (13), he reports his first conclusions to be justified by more data.

Fruwirth (43) criticises Bolley's work stating that he had found that large tubers were more likely to produce large tubers than were small tubers even from the same vine. He gives but few data warranting this conclusion, and I think that he overlooks Bolley's qualifying statement that "all must be normally mature."

In 1899, Remy (85) saw a part of the error* in the work of former German and French chemists who used physical methods for determination of specific gravity, and estimated their starch from this by Maercker's tables. He found that a great number of the tubers had hollows in their centers which seriously vitiated his results. With the idea of correcting this fault, he selected good smooth potatoes weighing about 200g. each and used about 70g. from the bud end for planting, while he determined the starch gravimetrically in the remainder by the use of Fehling's solution. The results for 1899 and 1900 show no definite relations between the nature of the seed tubers and the progeny either in dry matter or in starch content. This is the most exact experiment up to this time, although even the chemical method for starch determination leaves much to be desired. The starch fluctuations were rather narrow, however, running in 1898 seed from 76.0 percent to 81.6 percent calculated to the dry substance; and two crops are hardly sufficient to settle this question.

From 1899 to 1901 appeared the notable contributions of Fischer (33, 34, 35) to this subject. He showed that there was

*See writer's table of fluctuations in nitrogen content for further error.

a definite relation between the shape of tubers, and starch content and power to yield, and that such individual characters were in a great measure transmitted. The author believed that he was warranted in concluding that within a variety and under like conditions, flat-round tubers produce those richest in starch, but weakest in yielding power, while cylindrical-oblong tubers give a progeny poor in starch content but of greater yield. The explanation of the correlation between starch content and flat-round shape is from the following facts. The zone of highest content (see discussion concerning quality) in the potato lies next to the outside of the tuber. Other things being equal then, the tuber having the largest proportion of outer starch zone is the richest in starch. This is satisfied by the flat-round tuber.

In these investigations two varieties were used and selections made of rather small-flat-round tubers on one hand, and large-cylindrical-long tubers on the other. The former showed a specific gravity of more than 1.11 and the latter less than 1.10. These specific gravities correspond in Maercker's tables to more than 20 percent of starch in the former and less than 18 percent in the latter.

The results were as follows:

Variety.	Group.	Aver. weight seed tubers in grams.	Yield in kilos per hectare.	Yield kilos per ha. minus wt. of seed.
Sächsische Zwiebel	Flat- round, rich in starch.	60.6	21900	19900
	Cylindrical- long, poor in starch.	68.0	22600	20360
Reichs- kanzler.	Flat- round, rich in starch.	47.4	19900	18340
	Cylindrical- long, poor in starch.	62.5	25305	23290

In the year 1898 the experiment was continued in order to see if a transmission of the relationships under discussion was continued. For this reason both forms of tubers were selected from each group of the crop of 1897, giving in 1898 the following results:

Variety.	Form of tubers planted in 1897.	Form of tubers planted in 1898.	Aver. wt. of seed tuber in grams.	Yield of tubers in kilos per ha.	Yield of tubers in kilos per ha. minus wt. of seed.
Sächsische Zwiebel	Flat-round.	Flat-round....	40.0	18500	17180
		Cyl.-long.	89.5	21730	18780
	Cylindrical- long.	Flat-round....	40.0	19840	18520
		Cyl.-long.	70.0	22080	19700
Reichs- kanzler.	Flat-round.	Flat-round....	43.0	22620	21200
		Cyl.-long.	85.0	25440	22640
	Cylindrical- long.	Flat-round....	43.0	24060	22640
		Cyl.-long.	74.0	27970	25530

An inspection of the table certainly appears to show an inheritance of yield in tubers which had been selected the year before, the most notable being the increase of yield in the Reichskanzler variety where the long tubers from the long tubers of 1897 show such a remarkable gain over the long tubers from the round tubers of 1897, even though the seed weight of the latter is the greater. There are no final results on the starch content given. In his collected works (32) he states that a rise in starch content does follow selection of starch when determined by exact chemical methods. The author there concludes that the yield may be reduced by the continued selection of flat-round tubers which are rich in starch, and increased by selection of cylindrical-long tubers, which would be poor in starch.

Paulsen (79) makes a caustic criticism of Fischer's conclusions which may be summed up as follows: The form whether round or long is characteristic of the variety. According to Fischer's theory, a seedling plant showing round tubers should be rejected immediately because they are less capable of improvement. Nevertheless, we have many round varieties which continue to give exceedingly high yields.

In 1899 (40) and 1900 (41), Fruwirth reports that selection of tubers from high-yielding plants, as well as the choice of large tubers, affects the yield, and recommends the selection as a practical thing especially to keep up the vigor of the variety. In 1903 (42) the same author reports that a change in the general characteristics of the plants of a variety follows only gradually when the variety is brought from an acclimated place to one with a different soil and

climate. He argues that this in itself is a proof of hereditary transmission of a character acquired in the first place. Like results had been obtained already by Martinet (70).

Hess (56) concludes that selection of vigorous mother plants which produce many tubers will bring about an improvement in the yield. His data do not warrant a definite statement.

Brüner (14) in 1891 came to the same conclusions, but he observes that the choosing of high-yielding plants only increases the yield when planted on a fertile soil. When planted on a poor soil, such a strain will set many tubers but they will be small. He observes further that the use of vigorous, healthy plants as mother plants gives a noticeable protection from disease. A summary of his results is shown in the following table:

Variety.	Kind of mother plant.	Experiment 1.			Experiment 2.		
		Wt. of seed tubers g.	Yield kilos.	Diseased tubers percent.	Wt. of seed tubers g.	Yield kilos.	Diseased tubers percent.
Magnum bonum..	large	45-50	96	none	40-45	92	2
	small	45-50	77	none	40-45	65	3
Schnee-flocke...	large	35-40	55	6	35-40	61	8
	small	35-41	44	11	35-40	52	11

In 1895 Sempolowski (91a) reported an investigation in which he selected his seed potatoes from mother plants producing at least fifteen tubers, and planted them in comparison with such ordinary stock as would usually be planted. His yield from the selected tubers was 25285 Kg. per hectare compared with 24555 Kg. per hectare from the ordinary seed.

The experiments of Liebscher in which he came to negative results regarding hereditary transmission of tuber variations were continued at his death by von Seelhorst. The latter concluded in 1897 that their experiments up to that time contained some grave errors, such as unequal depths of planting, non-uniformity of seed as to type and size, etc. These errors were his warrant for starting new experiments which he has reported in three notable papers (89, 90, 91).

The experiments were with four varieties and I give below the collected results for the last year, 1903. The tubers used for seed are divided into two classes, large and small, which, as can be seen does away to a large extent with any influence due to differences in weight of the seed used. Determinations of starch in seed tubers and crop were also made and there was a notable transmission of starch to their progeny from high starch tubers.

Variety and kind of mother plant.	Large seed tubers.			Small seed tubers.		
	No. tubers used.	Aver. wt. g.	Aver. wt. of crop g.	No. tubers used.	Aver. wt. g.	Aver. wt. of crop g.
1. Phobus						
large yielding...	33	60.7	478	27	34.4	375
small yielding...	15	51.7	301	18	30.1	206
2. Frigga						
large yielding...	32	69.2	319	24	32.5	220
small yielding...	12	51.8	113 3	14	27.7	80.9
3. Viola						
large yielding...	25	65.3	372	22	36.6	314
small yielding...	23	65.2	282	17	30.8	177
4. Magnum bonum						
large yielding...	38	72.2	631	40	38.2	494
small yielding...	2	87.0	500	10	35.2	603

The exception in the case of *Magnum bonum* is explained by the fact that the seed of the crop from this variety was mixed in 1899 and the small potatoes used here may have been from large yielding vines before that. He concludes: "It is now without question to me, that we are able to raise the yield of potatoes by a not inconsiderable degree through the slight care in selection of seed, and also to prevent to a very great degree the degeneration of the newly improved variety."

Later Martinet (71), Krzymowski (62), Eustace (31) and Parisot (78) have experimented along this line, but they have not generally carried on their investigations long enough to warrant definite conclusions.

Summing up all evidence, it appears that there are variations which may be transmitted in tuber propagation, but that in practice a gain is rarely made by their selection. In general, results have been obscured by seasonal, climatic and local soil conditions which have a tremendous effect and which are not constant enough to permit tracing marked hereditary transmission. The changes that have been made in certain cases may be entirely due to mutations and not fluctuations; or they may be due to the comparison of tubers that were physiologically different, such as diseased and healthy, or immature and mature tubers. Proper conclusions can be drawn only after controlled experiments upon an accurately measured character by the use of biometrical methods.

6. HYPOTHESIS OF DEGENERATION

ANALYSIS OF THE QUESTION

Very closely linked with the possible improvement of varieties by the selection of favorable fluctuations, and its equal in economic importance, is the alleged phenomenon of degeneration. The common idea is, that there is a weakening, "a running out" of a variety, so that varieties within a greater or less number of years are certain to become worthless for cultivation. That certain varieties in certain localities do lessen in vigor from year to year is not to be disputed. The question is are there contributing causes; or is it an inner physiological weakening, a protoplasmic degeneration, which must take place owing to long continued bud propagation. The proper analysis of the question is of great importance; for, if such a degeneration must take place through obedience to physiological laws, our good varieties are necessarily doomed to a limited life. A proof that this is true, would make a great difference in the practicability of methods of tuber selection, where the improvement—if granted possible—would at least be slow. Methods of selection to change the composition, involving expensive analyses of mother tubers, as in the case of sugar beets, would be absolutely prohibited unless the sexual transmission of these acquired characteristics could be shown.

The common method of reasoning has been: Varieties have diminished in yield in certain places, and other varieties have been obtained. Nothing more is heard concerning the first varieties; hence, it is concluded that they have declined, and, figuratively speaking, died.

Hays (52) indicates the general belief in the following statement:

"The age to which a variety propagated by annually planting the root cuttings of a single seminally produced plant will live before the necessity of renewal by sexual reproduction is not known. But since standard varieties of potatoes remain prominent for only about a third of a century there is some reason for the belief that the varieties reach their period of old age or senility in that time."

The period of prominence of varieties is hardly a measure of the question, for hundreds of men are annually growing seedlings with which they hope to supplant current varieties and it would be remarkable if many old varieties were of sufficient merit successfully to hold their own. But nevertheless, even if the latter statement were not true, only a portion of the question is settled. Ehrenberg

(29) has lately discussed the question in all of its bearings from the practical standpoint, and divides it into three parts: (1) the aging (Altern) or senility of a variety, that is, a degeneration resulting from inner causes because of a prolonged and possibly unnatural propagation by means of tubers; (2) the deterioration (Ausarten) caused by a change to an unfavorable environment; (3) the loss of vigor due to lack of selection of the tubers (Herabzuchtung). It seems that the last two might be united, for, setting aside the first question, it must be variation in outside influences that causes sufficient variation in individual plants to make a basis for selection. We would then have the questions of variety senility, and of incomplete adaptation.

The latter question is one of such common knowledge that it is hardly necessary to discuss its voluminous literature. It should be noted, however, that this has nothing to do with the question of the inheritance of partial fluctuations.

In a letter written by Joseph Cooper (5), of New Jersey, in 1799, and published in volume one of the *Memoirs of the Philadelphia Society for promoting Agriculture*, the matter seems to be generally recognized. For fifty years, Cooper had maintained and improved without change, strains of pumpkins, early peas and asparagus. "He made similarly successful experiments in keeping and improving strains of the potato for even at that time the complaint was 'very general,' as he writes, 'that potatoes of every kind degenerate.'"

The idea has changed little among farmers today, although some light has been thrown on the question. In 1876, Beal (8) reported an experiment in which a variety giving good yields degenerated in eight years so as to produce nothing, although other varieties were producing good crops on the same soil. Fruwirth (42) and Martinet (70) have explained this and the other numerous experiments of the same nature by showing that there is a gradual change of characters that takes place upon changing the locality, either for better or worse conditions. In other words, a variety coming from a locality favorable as to soil and climate to one unfavorable, is not able to adapt itself rapidly to conditions, as are seed propagated plants by means of their possibilities for greater numbers of combinations of characters. Therefore there is a final disclosing of the inadaptability of the variety, although it takes place more or less slowly owing to the same law.

It seems to the writer that the main economic question still unsolved is whether there is a gradual reduction of disease resisting

power in varieties.* It has been commonly concluded from general observations by writers on potato culture that such is the case. There are varieties which in comparative tests with others, give small proportions of infected plants for a number of years and then show a notable increase in this proportion. This, however, may be easily explained. In plants propagated by seeds, when the vigor of any particular season's produce has been seriously impaired, the germinating power of the seed is likely to be affected and they are therefore either discarded for planting or fail to produce plants in the field, and the less vigorous strain perishes. With potatoes, an epidemic of any particular disease scarcely ever completely destroys the crop. The tubers weakened in vigor are planted the next season and may possibly produce plants less able to withstand the effects of further infection.

We have already seen the possibility of keeping up (not improving) varieties by selection, in the discussion concerning the transmission of tuber variations. Girard (45), who had probably a wider experience than any other investigator in the subject,—working as he did for eleven years with sometimes over six hundred co-operators,—sums up the whole matter as dependent on seed selection. However, the strict attention he paid to all matters concerning soil, fertilizers, planting and cultivation shows that he really laid great stress on favorable environment. He says:

"It is an opinion quite broadly held that varieties of potatoes cultivated continually in the same region, are certain to degenerate. It is a frequent thing to hear large potato buyers or starch manufacturers declare that after having imported and placed at the disposal of their growers varieties of potatoes noted for their large crops, they have seen them give excellent results the first year, fall away the second year, and give results even lower than the native potatoes in the third year. This is indeed true but it is by no means inexplicable; the degeneration which one sees in this circumstance, does not result from a natural weakening of the variety; it simply results from the entire lack of care with which the plants to be perpetuated are chosen. All the good tubers are sold to the market, and it is from the inferior, discarded tubers that has been demanded a continuation of qualities which they cannot give. I have demonstrated practically, and have established the fact that if suitable tubers are selected for planting and the cultivation accomplished with the needed care, the quality and quantity of the crop will be maintained under all satisfactory climatic conditions."

Since such degeneration as is commonly noticed can be readily explained without resorting to any hypothesis of "variety senility," this division of the subject is still to be discussed.

*It also may be that there is a natural selection of more virile strains of fungi.

BIOLOGICAL EVIDENCE

It has long been believed by a number of investigators that a conjunction of paternal and maternal nuclei is necessary for the "rejuvenescence of vigor" in the species. Life has been considered to be a cycle, running from conjugation to conjugation through a greater or less number of generations. This was considered by many to be definitely proved when Maupas (72, 73) showed that colonies of Infusorians, when artificially prevented from conjugating, invariably died out although often several hundred generations intervened. Later experiments along the same line by Calkins, however, have shown that a change in diet and the stimulus of a supply of chemical salts appear to be all that is necessary for continued propagation of Infusorians without conjugation. An addition of an extract of sheeps brains was all that was necessary to restore his colonies to full vigor after the 620th generation.

The classical experiments of Tichomiroff and Loeb have shown that artificial parthenogenesis may be induced by both mechanical and chemical stimuli; while Boveri and Delage have developed even non-nucleated ovum fragments to the larval stage. As one result of these facts, we must conclude that fertilization produces two results: a. A combination of hereditary qualities; b. A physiological stimulus to growth. But since other stimuli are found to produce cell division, it is hardly reasonable that highly specialized sexual processes should have been developed with the second result as their primary objects. Indeed Weismann (105 v. 1 p. 343) has concluded that the sole immediate effect of conjugation is "the combination of the hereditary tendencies of two individuals into one."

It appears that we have no data among wild plants from which we are compelled to conclude that continuous bud propagation is opposed to any natural law. Vines* writing of the Basidiomycetes says "These fungi are not only entirely asexual but it would appear that they have been evolved in a purely asexual manner from asexual ascomycetous or aecidiomycetous ancestors. The basidiomycetes, in fact, afford an example of a vast family of plants of the most varied forms and habits, including hundreds of genera and species, in which, so far as minute and long continued investigations have shown, there is not and probably never has been, any trace of a sexual process."

Late cytological investigations have shown sexual processes, or at least nuclear fusions similar to those of the higher plants and

*Vines, Nature 11: p. 625, quoted by Reid: Principles of Heredity.

animals, in some of these fungi; but there are other species, and among animals, some species of crustaceans, which reproduce exclusively by parthenogenesis. Some of the fungi are thought to have vestiges of degenerate sexual organs, and in the Crustaceans it can be demonstrated (105) that they once reproduced sexually, by their possession of the sac which once served for receiving the spermatozoa. It is extremely improbable that a process necessary or even advantageous to the continuance of any species could have been allowed to degenerate under the operation of natural selection.

In higher plants we have numerous examples where either no seed is produced or where seed propagation is seldom resorted to and yet we hear no serious charges of degeneration. Among them may be given the banana, hops, strawberry, sugar cane and many of the grasses. There are also certain parthenogenetic plants, such as the dandelion, that are certainly in no danger of dying out from their method of seed production.

The fact of degeneration in potatoes seems to have been explained as variety senility due to bud propagation, as a convenient prop to various hypotheses as to the function of sex; and this conclusion on theoretical grounds is decidedly unproved.

EXPERIMENTAL EVIDENCE

So far as I am able to learn the senility theory was first propounded about 1806 by Knight (61) although he did not lay special stress on potatoes. His hypothesis was that all varieties propagated by buds (particularly fruits) have a most productive period when they are of middle age and then become "subject at no very distant period to the debilities and diseases of old age."

Aitken (1) first applied the hypothesis to potatoes in 1837. He believed that although most fruits were produced from seed each year, a potato variety was a single plant propagated yearly through its tubers, and must grow old in the process. The first sign of this weakening of the variety, he says, is a lack of blossoms.

In Germany, Berchtold (9) in 1842 accepted Aitken's view with limitations. He considered that disease, climate, soil, cultivation and other conditions were the important factors to be considered.

Later Heine (53) of Emersleben, who was for ten years the chief German writer on potatoes, was very pronounced in his acceptance of Aitken's theory, and was followed by many of his countrymen. He speaks continually of "the unalterable law of nature that only through sexual seed propagation is it possible to

keep potato varieties lastingly high in yield." It is exceedingly interesting to note, however, that Westermacier (106) who succeeded Heine in his work has finally come to the conclusions that in Heine's results the contributing factors were not differentiated from the real question, and that it seems to him that it is questionable whether there is any such thing as variety senility.

The later conformers to Heine's views are Paulsen (43), Cimbal and Marek.

The first weighty objection to this theory was made by Julius Kühn (64) in 1871. He says: "The theory of a degeneration of the potato is disproved as untenable" and continued for several years thereafter to combat Aitken's theory. Busch (15) continued the opposition and seems to be really the first to recognize the true question. He says: "A degeneration in the sense of an increasing deterioration through the weakness of old age, does not exist." His views were endorsed and enlarged upon by Wollny (108), Liebscher (66), Girard (45), Thiele (96) and Fischer (33) who have all considered the question apart from that of degeneration through lack of adaptation to environment.

Ehrenberg (29) in 1904 makes a complete survey of data of Heine, of the deutschen Kartoffelkulturstation, and of Paulsen, the first and last of these running from 1877 to 1903. He discusses all the contributing sources of error and comes to the conclusion that "Ein Altern der Kartoffel gibt es aller Wahrscheinlichkeit nicht." And indeed, it appears that the people who have considered this *single* question are unanimous in opposition to the hypothesis of variety senility. The English and American writers do not seem to have considered the questions apart, although Bailey (5 p. 380) and probably others have recognized the division. He says:

"The presumption is that varieties propagated by buds wear out sooner than those propagated by seeds, for the experiments of Darwin and others have shown that the special office of seed propagation is to increase the virility of the species through cross fertilization. It must follow therefore, that in the absence of cross fertilization virility must be less.

"But we do not need to consider this phase of the question, for we are concerned with *variation* (that is, running out) rather than with *ultimate longevity* (or wearing out). Further, it is also probable that any tendency toward weakness through lack of fertilization is fully counterbalanced by the protection which such varieties receive under cultivation."

The work of the U. S. Agricultural Experiment Stations bearing the nearest relation to this question are those experiments dealing with comparative value of home grown and northern seed tubers. There is a wide spread belief both in this country and in

England that northern grown seed is the superior, and should be obtained every two years or so because of degeneration. It is interesting to note that in experiments at six stations* in the early nineties, all show results slightly in favor of home grown varieties. It is probable that in these experiments more care was paid to seed, fertilizers and cultivation than is usual to growers, resulting well for home grown seed; nevertheless, had the results been different, it would only have shown, either that the northern grown were better adapted to such climate or the soils there found, or that in coming from growers who made a commercial business of supplying seed tubers, they had been given better care in regard to selection and environmental conditions.

Relying for our conclusions on the philosophical grounds and the practical work of the German and French investigators, it seems tenable that there is no variety senility and that we are warranted in excluding this from our calculations as to commercial methods of producing varieties adapted to certain conditions. The more serious practical question, is the manner in which outside pernicious influences are to be avoided. As methods of cultivation and seed selection are pretty well established and soil, plant food and climatic conditions can be determined and partially controlled in each locality, it seems to the writer that here again the matter of disease control is the thing of primary importance. It is questionable, without disease resistance or comparatively certain disease control, if expensive work should be done to improve varieties in particular characters such as starch content, by selection of seedlings on the basis of a chemical analysis. For it is reasonably certain that we could not expect this improvement to be transmitted, if we were forced by loss of vigor due to disease attacks to return to sexual propagation. The latter, however, is a matter which we can say is yet unproved.

*Illinois, Vermont, Maryland, Georgia, Louisiana, and Missouri.

7. DISCONTINUOUS VARIATIONS

MUTATIONS

It has long been recognized that in potato varieties there sometimes appear marked bud variations which when propagated are true to type. If we accept DeVries' idea of mutations, and if we believe that bud mutations are of practically the same nature as seed mutation; then they may be either progressive, degressive or retrogressive. Such variations which have been noticed have always been relatively wide ones, but it is not inconsistent with the theory to have mutations which are within the limit of fluctuating variations. As the writer understands the question, these mutations may be either bud-mutations, which may not be propagated by seed; or mutations affecting the gametic structure, which will always be inherited unless new mutations intervene.

Darwin (21) mentions three cases, one in which a single white eye in the purple variety Forty fold, became the "parent" of a white variety. In another case this same variety produced a whole white tuber which bred true. The third case was that of the white Kemp potato which produced a red spot which was propagated and yielded a variety of much prominence, which was called Taylor's Forty-fold. In the United States there has been a number of varieties on the market for several years which have originated in this way. Among them are Thorburn's Late Rose, the White Victor and White Early Ohio. I should roughly estimate that less than 0.5 percent of our present varieties are from bud-mutation. The general belief is that these variations are confined to tuber color or possibly to tuber color and shape. Wohltmann (43) has offered an exception; a variation in flower color in the Leo variety although it was unknown whether the variety came from one or several seedlings. It certainly seems that the variations are almost always confined to the tubers, but this should be expected as the tubers are the modified part. The probability is that color is the only character that is easily gauged, and that if accurate methods of estimating other characters were used, they too would be found to vary. The supposed rarity of these occurrences has made them of little commercial importance, but it is very possible that with strict search, they might be shown to occur much oftener than is expected.

As stated before, data which I have collected appear to show that bud-mutations are usually—and possibly always—the loss of the dominant character of an allelomorphic pair, with the consequent appearance of the recessive character. This data will be published in a separate paper.

8. GRAFT-HYBRIDS

We have in graft-hybrids another method in which there may be a possibility of an improvement of the potato.

There is still a great deal of argument as to the authenticity of graft-hybrids which have been reported. The negative reasoning being chiefly theoretical, owing to their present inexplicability.

Darwin (21) collected a large number of cases where asexual hybrids of the potato seem to have been made. He himself was fully convinced as to their authenticity although he recognized the fact that the scoffer might attribute them to bud variation induced by the graft. He argues that the variation was always between the parent forms.

Daniel (19, 20) who has made by far the most extended study of grafts, says that, "While formerly it was considered that grafted scions lost none of their own characteristics and acquired no new ones from the stocks on which they were grafted, recent work indicates that this view must be modified." He states that hybrid-grafts can be fixed and propagated; and mentions the Edouard Lefort potato produced by vine graft of Majolin and Imperator and partaking of the character of each. He believes, however, that asexual hybridization is neither constant, regular nor very frequent.

Biffen (11) grafted tubers with different characters, and while convinced of the authenticity of the phenomenon, he states that "Tubers in which two types are blended, never occur." In halving the tubers transversely, each portion was indistinguishable from one of its parents. Each half of the tuber showed all the characters of one parent and not certain dominant ones. The graft-hybrid was in this respect different from the seed hybrid.

There is at present no cytological explanation of such a phenomenon, but from the apparent ease with which hybrid-grafts are made, or at least by which bud variations are caused through such stimulus, this seems to be a very interesting field for investigation. If in potato improvement we could in time learn to make a reasonable percentage of successful hybrids and the characters would blend, it might settle the quandary in which we are at present, in trying to get crosses with many of the excellent varieties which produce little or no viable pollen. On the other hand, if it finally proves that there is not a true hybrid formed, this method may still prove valuable as a means of obtaining bud-mutations.

9. QUALITY

HISTORICAL

In 1897 Coudon and Boussard (18) came to the conclusion on the ground of their tests with thirty-four varieties of potatoes that their culinary value is dependent upon the chemical composition, and that it varies directly as the nitrogen content and inversely as the starch content, that is culinary value = $\frac{\text{nitrogen}}{\text{starch}}$. Potatoes with a high starch content were disintegrated by boiling, and potatoes with a high nitrogen content resistant.

Their analyses were made of four physical divisions of the potato as shown in figures. These parts they designated, from outside to inside, as skin, cortical layer, outer medullary layer and inner medullary.

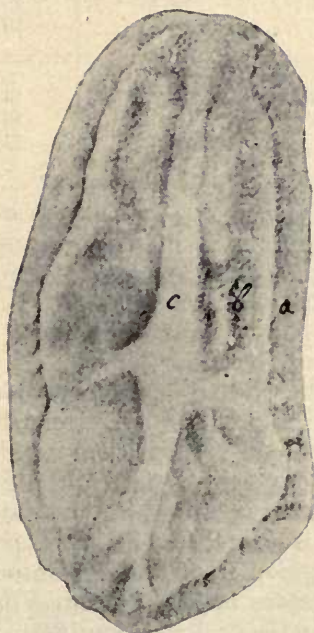


FIG. 5. ZONES OF THE POTATO. (AFTER COUDON AND BOUSSARD.)

- a. Cortical layer.
- b. External medullary layer.
- c. Internal medullary layer.

The outer skin is the colored portion and may be completely separated from the part underneath. The cortical or fibro-vascular layer lies next and is easily distinguished by the separating line of vascular bundles. In the interior the inner medullary layer appears

like an undeveloped stem branching out toward the eyes. The results of their analyses of these parts, calculated to the fresh basis are:

COMPOSITION OF THE DIFFERENT ZONES OF THE POTATO TUBER

Variety.	Zone.	Water.	Starch.	Total nitrogenous matter.*
Bleue geante.	Cortical.....	72.74	21.14	1.91
	Out. med.	74.33	19.78	1.88
	In. med.	81.72	12.30	2.14
Czarine.	Cortical.....	72.92	22.45	1.84
	Out. med.	78.87	15.64	2.17
	In. med.	84.48	10.50	2.17
Saucisse.	Cortical+ Epidermis	78.72	14.38	2.22
	Out. med.	79.12	13.47	2.39
	In. med.	80.73	12.31	2.62

The water and nitrogen contents increase as we go from the outer to the inner zones, while the starch content decreases. It is also interesting that the percent of proteid nitrogen to the total nitrogen decreases in the inner zones; the former being 68.7 percent in the cortical layer, 56.0 percent in the outer medullary layer and 47.3 percent in the inner medullary layer.

This work was believed to give a chemical basis for the selection for planting, of tubers which were of better table quality. It should be noted, however, that the standard for table quality in France is decidedly different from that in the United States. The accepted method of cooking there is frying in deep fat, for which a potato which holds its form is desired; while in this country probably nine-tenths of the consumption is of boiled potatoes, which are desired dry and mealy. Potatoes imported from Vilmorin, which I have examined, nearly all possessed a yellow flesh, a strong flavor, and were firm and soggy after boiling.

Shortly after the appearance of this work, Frisby and Bryant (38) reported separations and analyses of these different zones in the American variety "White Star," without separating the outer and inner medullary layers, and found the following composition:

Zone	Water percent	Proteid N.	Total N.	N. free extract
Cortical layer	83.2	.24	.36	12.6
Outer and inner Med.	81.1	.18	.32	15.7

*Probably total N x 6.25 although it is not stated.

These results are in direct opposition to Coudon's and Bousard's as to nitrogen and starch but the discrepancy may have been due to the different methods of determination. Nitrogen free extract gives total carbohydrates minus crude fibre, at all times, while a direct starch determination is very different when made in the fall from one made in the spring when large quantities of starch have been changed to sugar.

In 1901 Waterstradt and Willner (104) reported extended investigations on the same subject. Their results are more applicable to American conditions for the reason of similarity of standard of quality in Germany and America. Nine varieties were used, each of which was grown on two separate fields. Of these varieties, three were recognized to be of good table quality, three were coarse starch producing varieties and three were on the border line between the two. I give here the average composition only of the first and second classes:

Place grown.	Class.	Zone.	Fresh basis.			Dry basis.		
			Dry mat.	Tot. N.	Starch.	Dry mat.	Tot. N.	Starch.
Berlin Exp. Field.	Eating var.	Cor....	24.3	0.336	18.17	100.	1.34	75.03
		Med...	19.8	0.363	14.74	100.	1.85	74.50
	Coarse starch var.	Cor....	26.9	0.359	20.61	100.	1.34	75.68
		Med...	23.1	0.355	17.76	100.	1.55	76.87
Marien Field.	Eating var.	Cor....	27.3	0.365	.....	100.	1.35	.....
		Med...	24.1	0.391	.....	100.	1.56	.....
	Coarse starch var.	Cor....	30.6	0.354	.....	100.	1.17	.....
		Med...	27.3	0.383	.....	100.	1.42	.....

This table shows that potatoes of better table quality are markedly lower in starch than the others, as was to be expected from the German classification. The dry matter in the cortical layer is regularly higher than in the medullary layers, as is the starch content when calculated to the fresh basis. When calculated to the water free basis, however, the starch variations are slight. The total nitrogen variations corroborated the results of Coudon and Bousard.

In order to find the proportion of cortical layer and inner medullary layers, the authors cut the potatoes in half through the long diameter, marked the line of demarcation of the two layers on paper and weighed the corresponding slips.* The average of all of the good eating varieties in proportion of cortical layer to inner medullary layers was 100:121.5, while the proportion in the coarse varieties was 100:140.4. The actual cooking tests bore out their opinion of the relative cooking value of the varieties as expressed in their classification, and they concluded that chemical composition could not be used as a basis of selection for cooking value.

In 1905 Gilmore (44) published an excellent paper in which he tentatively concluded that the culinary value of the potato depended not so much upon its chemical composition as upon its anatomical and perhaps its physiological structure.

EXPERIMENTAL.

COMPOSITION OF DIFFERENT PARTS

The first object in this work was to see if American varieties and especially if within a variety, the table quality is dependent upon the total nitrogen content.

The two varieties Rural New Yorker No. 2 and Carman No. 3 were selected as being representative popular varieties. Careful mechanical separations of the different zones were made in five individual potatoes of each variety, after the manner of Coudon and Boussard. Dry matter was determined at 104 degrees C in a current of hydrogen, and total nitrogen was determined by the regular Kjeldahl method, as were all similar determinations here reported. The averages of the results of each variety are shown in the following table:

TABLE 3. COMPOSITION OF PARTS OF THE POTATO

Variety.	Zone.	Dry matter, percent.	Tot. N. fr. bas., percent.	Tot. N. dry bas., percent.
Rural N. Y. No. 2.	Cortical.....	20.95	0.46	2.20
	Outer med	18.46	0.47	2.56
	Inner med.....	14.04	0.45	3.23
Carman No. 3.	Cortical.....	22.20	0.49	2.23
	Outer med....	19.41	0.51	2.63
	Inner med	14.92	0.52	3.49

*This method does not show the correct relation. If the potatoes were considered as spherical, the relation would be (whole diameter)³:(medullary diameter)³: (medullary diameter)³.

The content of dry matter is quite variable and regularly decreases from the outside to the inside of the three zones. The total nitrogen content is only slightly variable in the three zones, though showing a regular increase to the inner medullary layer, when calculated to the dry basis, owing to the variability of the water content. Ash determinations made on ten samples varied little from 0.90 percent on the fresh basis, showing that carbohydrates, estimated by difference, are higher in the cortical layer, and quite low in the inner medullary layer. From this we may conclude that there is a difference in time of cooking in the different zones of the potato, and that the glistening appearance of the cortical layer after boiling would be accounted for by its larger starch content breaking open the cell walls.

SAMPLING

Since there is such a difference in the composition of these different zones, it is extremely difficult to obtain a correct sample of the tubers for analyses without spoiling them for cooking tests or for planting. A number of methods were tried, the one giving the most satisfactory results being that of a cylinder cut with a twelve mm. cork borer, parallel to the long diameter, but a little to the side. This takes in only a portion of the inner medullary layer and compares well with the composition of the whole potato. The greatest difference in five determinations of total nitrogen on individual tubers was 0.04 percent calculated to the fresh basis.

TABLE 4. VARIATIONS IN SAMPLING

Potato No.	Total N. per cent in cylinder.	Total N. in whole tubers.
1	0.37	0.34
2	0.43	0.41
3	0.49	0.50
4	0.42	0.43
5	0.46	0.44

This method has been used in all subsequent determinations when tubers were to be used for cooking tests for planting.

RELATIONS OF TOTAL NITROGEN CONTENT AND QUALITY

To ascertain the relation of total nitrogen content to quality, a number of tubers of the Rural New Yorker No. 2 variety in which

total nitrogen and dry matter had been determined, were tested by boiling. Corks were tied in the holes, whence the sample for analysis had been taken. City water from artesian wells, containing a considerable amount of salts, was used, but no sodium chlorid was added. On account of the amount of work necessary to secure samples with a sufficient variation in nitrogen content, only ten of each kind were used. So small a number makes the probable error large, especially as no method of judging the quality has been devised except an arbitrary personal judgment. The flavor and the table quality aside from flavor were judged, dividing the array into five different classes.*

Their selection for high nitrogen content did not seem to affect the average of the two classes in weight or dry matter to any considerable extent, as is shown below :

TABLE 5. QUALITY OF HIGH NITROGEN POTATOES

AVERAGES: Wt. 206g. PERCENT DRY MATTER 21.09. PERCENT N. DRY BASIS 2.27

Potatoes used.	Average total N. content.	Quality and appearance.					Flavor.				
		good.	fair.	med.	poor.	very p.	good.	fair.	med.	poor.	very p.
10	0.48	1	5	2	1	1	0	3	5	2	0

TABLE 6. QUALITY OF LOW NITROGEN POTATOES

AVERAGES: Wt. 218g. PERCENT DRY MATTER 21.99. PERCENT N. DRY BASIS 1.62

Potatoes used.	Average total N. content.	Quality and appearance.					Flavor				
		good.	fair.	med.	poor.	very p.	good.	fair.	med.	poor.	very p.
10	0.36	1	4	2	2	1	1	3	4	2	0

The tables indicate that variation in nitrogen content does not have a noticeable effect on quality, although there is a slight indication that extremely high nitrogen might make the flavor more pronounced. High nitrogen potatoes can therefore be propagated without correlation adverse to quality, weight or dry matter.

*It should be noticed that in these tests by arbitrary standard only the results of any one experiment should be compared with each other, for it is impossible to keep in mind an arbitrary standard from week to week to compare separate tests. The tubers in every case were known by numbers only.

RELATIONS OF DRY MATTER AND QUALITY

In the same manner as above, selections of potatoes of different dry matter content were tested. As far as was possible tubers of relatively the same weight were used, in order to have the same time of cooking. Otherwise the selection was entirely by dry matter:

TABLE 7. QUALITY AS RELATED TO DRY MATTER

Potatoes used.	Dry matter.	Average total N. fresh b.	Average wt.	Quality other than flavor.					Flavor.				
				g.	f.	m.	p.	v. p.	g.	f.	m.	p.	v. p.
8	16-17% Aver. 16.50	0.40	219	0	0	1	3	4	0	0	0	2	6
10	17-18% Aver. 17.56	0.42	232	0	2	3	3	2	0	0	1	6	3
10	19-20% Aver. 19.62	0.45	228	2	4	4	0	0	1	3	4	2	0
10	21-22% Aver. 21.65	0.44	204	1	4	3	2	0	1	5	4	0	0
10	23-24% Aver. 23.44	0.44	220	2	4	4	0	0	1	4	5	0	0
8	25-28% Aver. 26.09	0.38	208	1	3	3	1	0	2	3	3	0	0

This table shows that there is a lower limit in amount of dry matter or more probably of carbohydrates, below which tubers cannot be of good quality. In this variety it is about 18 percent dry matter or probably about 15 percent starch.

When the dry matter is above this lower limit, the quality does not seem to be directly affected. It may be that this lower limit is different in different varieties, and that owing to the general low dry matter of these samples the standard of quality was put too low. However some excellent potatoes were found with a total dry matter as low as 19 percent.

Waterstradt and Willner showed that in certain German varieties those tubers with very high starch content were of coarse qual-

ity. We found no potatoes nearly up to this limit, but from general experience we should conclude that potatoes with a starch content above a certain limit would easily fall to pieces, or if the cell walls were strong enough to hold together under such pressure, they must necessarily be coarse and woody.

PHYSICAL STRUCTURE AND QUALITY

The writer was led first by Coudon's and Boussard's work to believe that the physical structure held some relation to the table quality. Microscopical examination of the structure of the potato bears out the chemical analyses of the different zones.



FIG. 6. a. OUTER SECTION OF CORTICAL LAYER. b. INNER SECTION OF CORTICAL LAYER.

(Figures 6 and 7 from the same tuber.)

The cortical layer (figure 6), below the first few layers of cells which are removed with the skin, shows a remarkably larger amount of starch in the cells, than does the internal medullary layer (figure 7). The starch content of the external medullary layer is also greater than that of the internal. The grains of starch in the cortical and external medullary layers besides existing in greater numbers per cell, are generally of larger average size. The paucity of starch in the internal medullary layer causes the cells to be only partially filled with the cooked starch and the cell walls are scarcely ever ruptured. In the cortical layer, on the other hand, the amount of starch is such that in the swelling due to cooking, the cells are filled completely and many of them ruptured, causing the mealy appearance so much desired by the consumer.



FIG. 7. a. SECTION NEAR THE VASCULAR BUNDLES SHOWING PORTION OF EXTERNAL MEDULLARY LAYER. b. SECTION OF INTERNAL MEDULLARY LAYER.

It is quite evident then that potatoes having as far as possible a homogeneous flesh and containing as large an amount as possible of cortical and outer medullary layers in proportion to inner medullary layer, should be of the finest quality.

This has been shown to be a fact in experiments with fifteen American varieties even though cooked after having been split* in half, which is manifestly a disadvantage.

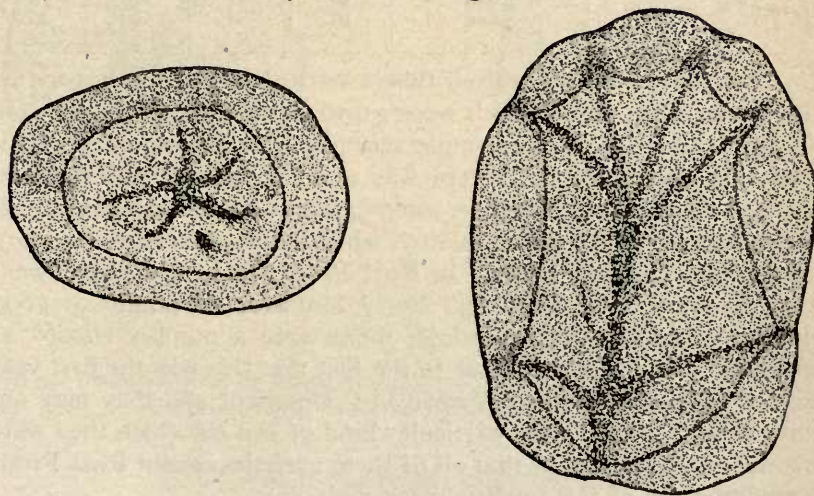


FIG. 8. CROSS SECTIONS OF POTATO OF GOOD QUALITY. LARGE CORTICAL AND EXTERNAL MEDULLARY LAYERS, AND SMALL OR FINELY DIVIDED INTERNAL MEDULLARY LAYER.

*In a number of these tests the halves of the potatoes were fastened together again before cooking, in order to make the test as near as possible like ordinary practice. The judgment of the quality was made by two different persons. The tubers were known only by number.

TABLE 8. PHYSICAL SELECTION OF POTATOES FOR TABLE QUALITY

Variety.	Selected physically for quality.	No. tubers used.	No. tubers good qual.	No. tubers med. qual.	No. tubers poor qual.
E. Six Weeks.....	good	10	8	2	0
	poor	10	1	3	6
E. Ohio.....	good	10	10	0	0
	poor	10	2	3	5
Houlton Rose.....	good	10	9	1	0
	poor	10	0	2	8
Irish Cobbler.....	good	10	10	0	0
	poor	10	3	2	5
Minister.....	good	10	7	3	0
	poor	10	2	3	5
Carman No. 3.....	good	20	16	3	1
	poor	20	4	5	11
Rural N. Y. No. 2...	good	20	16	4	0
	poor	20	5	5	10
Green Mountain....	good	20	16	2	2
	poor	20	3	7	10
State of Maine.....	good	10	12	8	0
	poor	10	2	10	8
Gem of Aroostock...	good	10	8	10	2
	poor	10	0	10	10

From fifty to one hundred tubers were used in making each of these selections, all of which were grown on the same type of soil, (a light sandy loam), in a single acre plot. In making selections it was very noticeable that there was a great varietal difference in quality. As the table shows, in some varieties it was very easy to select tubers of good cooking quality, while in other varieties no sharp distinctions could be made. In Rust Proof, Ionia seedling, Twentieth Century, Gold Coin and Early Manistee no potato of good quality could be found although there were a number classed as medium. This is perhaps due to the fact that this was the first year any of the stock had been grown in Connecticut and they may not have been adapted to the particular kind of soil on which they were grown. I have learned that all of these varieties except Rust Proof sometimes are of fair quality in other places.

It seems evident from Table 8, that this anatomical difference is a varietal character, the difference between varieties being very great. The difference in quality within the variety, however, with as similar environmental conditions as it was possible to give, is almost as great as the difference between varieties.

Unfortunately this method cannot be used in selecting potatoes for the table, on account of the necessity of their cutting. Whether the extreme variations toward homogeneous structure are correlated with quality to a sufficient degree to be used as a means of improving varieties in quality; or whether fluctuations due to slight environmental differences impossible to control, obscure the heritable variations, is now being investigated. There still remains the possible explanation that the other factors influencing quality are the causes of the great varietal differences, although our work indicates that this is not probable. We hope that it will be possible to use the method in determining the rejection of seedlings after a cross. The tubers from the different first year plants should be kept in different bags and at planting time selections made of those tubers having a large cortical layer and a small internal medullary layer branched in fine divisions,—the idea being to have the internal structure of the potato as homogeneous as possible.

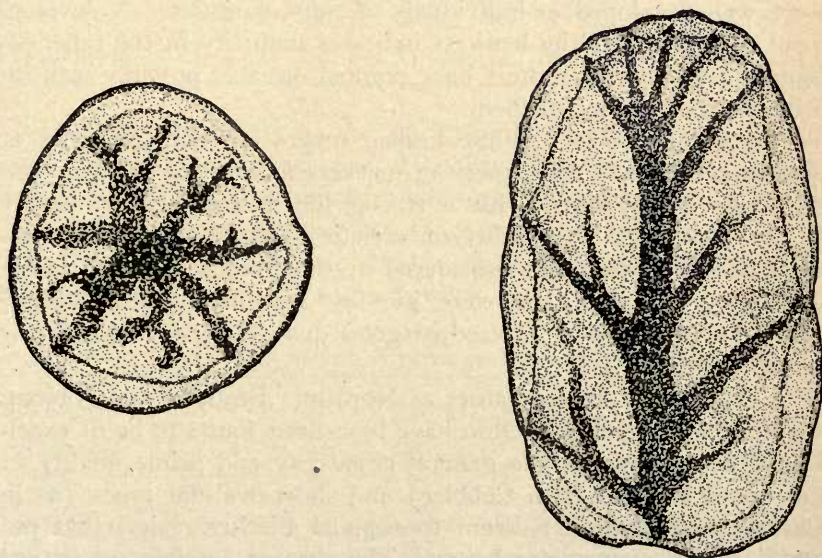


FIG. 9. CROSS SECTIONS OF POTATO OF POOR QUALITY. SMALL CORTICAL LAYER AND LARGE THICK INTERNAL MEDULLARY LAYER.

OTHER FACTORS INFLUENCING QUALITY

1. *Color of skin.*—Potatoes from seedlings of a single cross varying in color of skin to white, light brown, pink and red did not show any greater variation in quality than did those of a single color. Hence it may be concluded that color is not correlated with

quality. We found varieties of all colors except the purple types which were of good quality. No purple skinned potatoes were available which were of a size that indicated maturity and this might account for the fact that they were of a poorer quality.

2. *Nature of skin*.—Those varieties which have a netted skin were found to be generally smooth-skinned when immature. A corky appearance indicated both maturity and a better keeping quality. In some cases one end of the tuber had a corky netted skin while the other end was smooth; these were generally different in internal structure, indicating some obstruction to perfect development. Very rough-skinned varieties as Russet and Scabproof were in general less susceptible to infection with potato scab, but were neither of better quality nor of higher starch content than other varieties grown under the same conditions; which is in opposition to the conclusions of Krzymowski (63).

Lenticels were found to be present in all sizes of potatoes and were well developed in individuals of most varieties. A development of strong healthy lenticels indicates maturity in the tuber although a number of writers have pointed out that possibly scab inoculation takes place in them.

3. *Color of flesh*.—White fleshed tubers are the only ones at present accepted in the American markets and it may be that yellow flesh is correlated with a strong flavor and a poor quality by our standard. A number of varieties with a yellow flesh imported from France and considered by the French to be of prime quality were tested and were gummy and hard after boiling. These varieties are considered of good quality for frying and for use in salads.

4. *Shape*.—Round potatoes as Noroton Beauty, and oblong round potatoes as Early Ohio have both been found to be of excellent table quality, but the general popularity and prime quality of the round flat (as Irish Cobbler) and short-oval-flat types (as in Carman's productions), seem to support Fischer's view that potatoes of these types are better. The greater possible percentage of cortical layer in these types seems to be sufficient reason for the conclusion, but there is a further argument in the fact that salad potatoes are usually small round types, or long slender types as the Lady Finger.

5. *Depth and frequency of eyes*.—Great depth of eyes will be avoided because of the waste in peeling. A number of writers have also stated that extremely deep eyes tend toward coarseness of the variety, and indeed this seems to be the case. The vital-

ity of the sprout produced varies directly as the size and depth of the eyes, which is worthy of note in selection, otherwise types might be bred with eyes too shallow.

The number of eyes has a marked effect on the quality, due to the fact that the internal medullary extends a branch to each eye. This makes the quality, other things being equal, vary inversely with the number of eyes. This variation within the variety is very great, varying in a count of 219 tubers of Rural New Yorker No. 2 from 7 to 28.

In 1902, in the course of this work, 189 tubers of the variety Rural New Yorker No. 2 had been analyzed and a large number having been cooked were found to be of very good quality although the average dry matter content was only 20.74 percent. The modes for eyes in this lot was 12.

TABLE 9. VARIATIONS IN NUMBER OF EYES IN RURAL NEW YORKER NO. 2, 1902

No. of eyes	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Frequencies	3	4	9	15	21	32	15	20	13	19	12	13	6	4	2	1

In 1903, 219 tubers of the Early Ohio variety were used, and were found to be of much poorer quality than those used in 1902, though of similar size and of pleasing appearance. The average dry matter content was only 16.15 percent or 4.59 percent lower than the others. *The mode for the number of eyes was here 15 as compared to 12 in the better variety.*

TABLE 10. VARIATIONS IN THE NUMBER OF EYES IN EARLY OHIO, 1903

No. of eyes	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Frequencies	1	4	2	6	21	21	25	36	37	17	12	15	7	11	2	2

6. *Type of soil.*—It is well known that the physical type of soil best suited for the growth of potatoes is a light sandy loam. These investigations from 1902-1904 were carried on in the black heavy loam characteristic of the corn belt of the central west and in 1905-1906 on a light sandy loam in Connecticut. No stock from the same strain was available for test, and as the influence due to climate and soil is unknown, we have scarcely a warrant to make comparisons. Published analyses, however, show a higher percent of dry matter in potatoes grown on the light sandy loam, and the quality of tested tubers from the same variety

though not from the same stock, was perceptibly better on this type of soil. In a test of Early Ohio potatoes on the heavy loam soil, planting to a depth of five inches gave potatoes of a much better quality than potatoes which were planted to a depth of three inches. The same was true of Carman No. 3 planted on a light sandy soil, but potatoes planted three inches deep and ridged at the last cultivation were of poorer quality than those unridged. This coincides with Gilmore's extensive work where he found that about five inches depth showed a more uniform temperature during the season than did other depths.

7. *Season and climate.*—Season and climate are undoubtedly factors in determining quality, though whether they have an influence beyond that of giving the plant greater or less chance for producing healthy, mature tubers, it is impossible to say. As potatoes are known to have a very great range of altitude and latitude when conditions of soil are right, we are inclined to think that the latter is the only influence.

8. *Influence of fertilizers.*—The influence of fertilizers seems to be primarily if not solely due to their aid in producing a normal development of tubers. That is, the fertilizer applied must correct abnormality by furnishing an element of fertility which is lacking in the soil. An application of ordinary quantities of an essential element which is already present in the soil in amounts necessary to a normally fertile soil, probably has no marked effect either upon the crop or its quality.

Some writers have maintained that the use of potassium sulfate gives potatoes of better quality than are produced with the use of potassium chlorid, but this conclusion is opposed by other experiments. There is probably no ill effect from the use of ordinary amounts (100 to 500 lb.*) of potassium chlorid, even if excessive use of chlorids is detrimental.

The following table shows the general effect of fertilizers upon quality. In an experiment planned primarily in soil fertility, sodium nitrate was sown at the rate of 250 lb. to the acre over the whole plot and potassium and phosphorus supplied as shown in the table. The numbers here shown are the estimates of quality of all of the tubers produced by all of the plants of one row running across all the plots. The variety used was Green Mountain. The land was very poor in fertility although in excellent

*Potatoes of excellent quality have been tested, which were grown with this rate of potassium chlorid but no comparisons were made with like amounts of potassium sulfate.

physical condition for growing potatoes. It was known, however, that it was not nearly so deficient in phosphorus as in potassium. As is seen, the quality grew markedly better where the potassium chlorid was supplied at the rate of 300 lb. per acre, but apparently very little difference was made by doubling the applications of phosphorus.

TABLE II. INFLUENCE OF FERTILIZERS ON QUALITY

Plot No.	Fertilizers applied per acre.	No. tubers produced.	No. of tubers of each of these qualities.				
			Good.	Fair.	Medium.	Poor.	Very poor.
1	Nothing.	81	0	5	17	25	34
2	Potassium chlorid 150 lbs., Bone meal 200 lbs.	125	1	10	33	56	25
3	Potassium chlorid 300 lbs., Bone meal 100 lbs.	121	1	12	42	40	26
4	Potassium chlorid 300 lbs., Bone meal 200 lbs.	148	3	14	56	45	30
5	Potassium chlorid 300 lbs., Bone meal 400 lbs.	135	3	19	56	37	20

The explanation of this fact is apparent, I think, in the next table, which shows the number of tubers produced of different classes of 30 grams each. There was simply a more nearly normal development of the tubers in the last three plots, due to the availability of more potassium.

9. *Degree of maturity.*—In 1902, a number of potatoes of Rural New Yorker No. 2 variety, of different degrees of maturity, were analyzed. The determinations showed that the greater part of the total nitrogen is developed early in the growth of the tuber, while the starch is stored up later. A microscopical examination showed that the starch grains in the cells of the immature tubers are small in size and few in number. Starch grains in the cortical and outer medullary layers of mature tubers averaged about 75 μ . and were found as large as 105 μ .; while in immature tubers of less than an ounce in weight, the starch grains averaged only 25 μ .

TABLE 13. COMPOSITION OF TUBERS OF DIFFERENT DEGREES OF MATURITY
AVERAGES OF A NUMBER OF TUBERS

*Degree of maturity.	Dry matter, percent.	Protein fresh basis, percent.	Protein dry basis, percent.
Very immature.....	8.01	1.22	15.23
Immature	11.15	1.66	14.93
Fairly mature.....	16.70	2.15	12.85
Mature.....	21.20	1.94	9.16

These tubers,—as might be expected from their composition,—increased in desirability for table use with maturity to such an extent that we may conclude that all immature potatoes should be rejected for cooking.

This fact seems a reasonable explanation of the influence that certain other minor factors seem to have on quality, such as distance apart and time of planting, depth and frequency of cultivation, etc. In fact any and all of the conditions of environment that lead to the normal development of healthy, mature potatoes may be considered as contributing toward their table quality.

As a result of these tests, we are led to the following conclusions regarding quality:

1. Quality depends upon the following factors: a. Homogeneous anatomical structure. In general, quality increases with the thickness of the cortical layer, and decreases as the number of eyes increases. A variety shape which gives a chance for a large ratio of cortical to inner medullary layer, is an advantage b. Dry matter content. This must be such that the cooked starch fills the cells to their bursting point. The lower limit is roughly estimated at 18 percent. c. Maturity. This is affected by all

*Weights of the different classes were approximately 50 g., 909 g., 150 g. and 250 g.

factors of soil physics, soil fertility, cultivation and climate during the growing period.

2. Under like conditions of environment, variations in quality are shown as varietal characteristics due to heritable differences in shape, composition and physical structure.

3. These heritable differences can probably be used as a basis for improvement in quality when originating new varieties.

4. There are also variations in quality within a variety which are in large measure due to immediate external conditions. These fluctuations obscure the heritable variations upon which improvement depends.

5. The question as to whether partial fluctuations of these characters obey the same laws as individual fluctuations, and whether temporary improvement can be made through their selection is yet undecided. The truth of Johannsen's theory of the fluctuations of "pure lines" would answer this in the negative.

VARIATION OF THE POTATO IN CHEMICAL COMPOSITION AS A BASIS FOR ITS IMPROVEMENT

In 1902 work was started to determine whether there were sufficient variations of the proteid content within a variety of potatoes to warrant selection of individuals high in protein to endeavor to raise the average protein content of the variety. It was expected later that this work would throw some light upon Johannsen's theory that in "pure lines" (self-fertilized lines), fluctuations regress completely to the mode of the pure line and not toward the mode of the general population. If this is true, absolutely no change could be made by selecting partial fluctuations. Johannsen's work was not reported until after the results of these two seasons had been obtained, but the data are here reported just as it was collected in 1904.

About two bushels of potatoes of uniform type were selected from a carload of the variety Rural New Yorker No. 2. They were all grown in the same county in Wisconsin, but it could not be definitely stated that they were all grown in the same field or upon the same type of soil although the latter is likely. They were of good appearance and average 223 g. in weight. The smallest potato used weighed 141 g. and the largest 328 g. Over one-half of the tubers varied less than 30 g. from the average. The table quality was good for the time of the year, it being the month of May.

Total nitrogen, dry matter and specific gravity determinations were made on one hundred seventy-nine tubers. The total nitrogen was determined by the regular Kjeldahl method; dry matter by drying to constant weight at 104°C in a glycerol oven in a current of hydrogen; and the specific gravity by the weight in air and the weight in distilled water at 20°C. Considerable variation was shown in the content of the dry matter and the average was found to be very low for potatoes of such good quality. This condensed table shows the extent of the variation, the extremes being 15.18 percent and 28.27 percent.

TABLE 14. VARIATION IN DRY MATTER IN RURAL NEW YORKER NO. 2, CROP OF 1901

Dry matter, percent.....	15-16	16-17	17-18	18-19	19-20	20-21	21-22
Frequency.....	1	7	9	17	32	39	34
Dry matter, percent.....	22-23	23-24	24-25	25-26	26-27	27-28	28-29
Frequency.....	18	11	3	5	2	0	1

For calculating total nitrogenous matter we have used Frisby's and Bryant's (38) factor of 5.5 times the total nitrogen. The proteid nitrogen is probably about 55 percent to 60 percent of these numbers, but as it is still questionable as to what dietetic value should be placed upon non-proteid forms of nitrogen, they were not determined. The total nitrogenous matters are reported, calculated to the water free material. The extremes are 6.63 percent and 15.69 percent.

TABLE 15. VARIATION IN TOTAL NITROGENOUS MATTER IN RURAL NEW YORKER No. 2, CROP OF 1901. DRY BASIS

Nitrogenous matter in percent..	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16
Frequency.	3	4	7	18	33	43	30	23	12	6

This table shows a surprising variability in composition in potatoes of the same variety. The extremely high percentage of nitrogenous constituents shows that there may be a basis for the origination of a variety equal in proteid content to a number of the varieties of dent maize now grown, could a variety with the composition of the highest fluctuations be perpetuated. Certainly, in this variety at least, the tubers do not deserve to be ranked as solely a starch food.

A number of points were observed in looking over the complete data which are too bulky to publish.

1. The nitrogen content does not vary directly with the number of eyes. Therefore, in potatoes of the same size, many stems have no greater amount of nitrogen to draw upon in sprouting, than have a few.

2. Variations in nitrogen content are not correlated with particular shapes.

3. Smaller, younger tubers are richer in nitrogen; that is, there is stored early in the formation of the tuber a relatively larger proportion of the total nitrogen than of starch.

4. The error in determining starch from specific gravity tables is much greater than is generally supposed. For example, tuber No. 82 contains 14.32 percent nitrogenous matter, specific gravity 1.090; while tuber No. 69 contains 7.39 percent nitrogenous matter, specific gravity 1.091.

SELECTIONS FOR PLANTING, 1902

To endeavor to determine whether these fluctuations in a chemical constituent are transmitted by tuber propagation, two plots were planted, one of high nitrogen selections and one of low nitrogen. This gives a check upon the seasonal and soil variations. The selections were made upon the fresh substance, because this is their market condition, and because the dry matter determinations were not finished soon enough to make selections on the water free basis practicable.

As may be seen in the table, potatoes were chosen with as nearly as possible the same average weight. The low protein selections, however, averaged about 18g. heavier per tuber.

The average nitrogenous matter in the high portein plot was 2.95 percent of the fresh substance and 14.07 percent calculated to the water free substance. The following data were taken on each tuber. The long, medium and short diameters give a fair indication of the shapes of the tubers:

TABLE 16. HIGH PROTEIN SELECTIONS IN 1902

No.	Wt. per cent.	Long diam.	Me- dium diam.	Short diam.	No eyes	Specific gravity.	Dry matter percent.	Nitroge- nous matter, fr. b. percent.	Nitroge- nous matter, dry b., percent.
44	246	98	75	55	10	1.095	22.09	2.93	13.28
63	279	115	68	60	14	1.082	19.49	3.05	15.69
68	178	90	65	53	11	1.090	21.02	2.95	14.03
80	198	88	70	55	9	1.097	20.74	2.99	14.44
82	232	100	68	52	12	1.090	20.62	2.95	13.29
99	182	95	60	55	16	1.088	22.21	2.95	13.29
104	294	122	70	58	17	1.091	21.21	2.87	13.54
107	228	115	62	52	18	1.096	21.41	2.90	13.53
111	155	75	62	55	7	1.095	22.41	2.90	12.94
113	221	98	65	58	19	1.088	19.19	2.91	15.16
117	141	90	57	46	13	1.100	23.31	3.09	13.25
129	199	91	66	54	12	1.087	19.75	2.84	14.41
137	177	85	63	48	10	1.096	20.98	2.90	13.79
147	166	90	64	50	10	1.088	20.45	3.12	15.30
166	190	90	65	51	11	1.098	20.84	2.95	14.13
Aver.	205.7				12.6	1.092	21.05	2.95	14.07

Each potato was quartered and each quarter planted in a hill. The hills were four by two feet apart. The planting could not be done on account of press of other work until June tenth.

In exactly the same manner, end to end with these selections, were planted the following low protein selections, which averaged 1.78 percent nitrogenous matter in the fresh substance, and 8.75 percent calculated to water free basis.

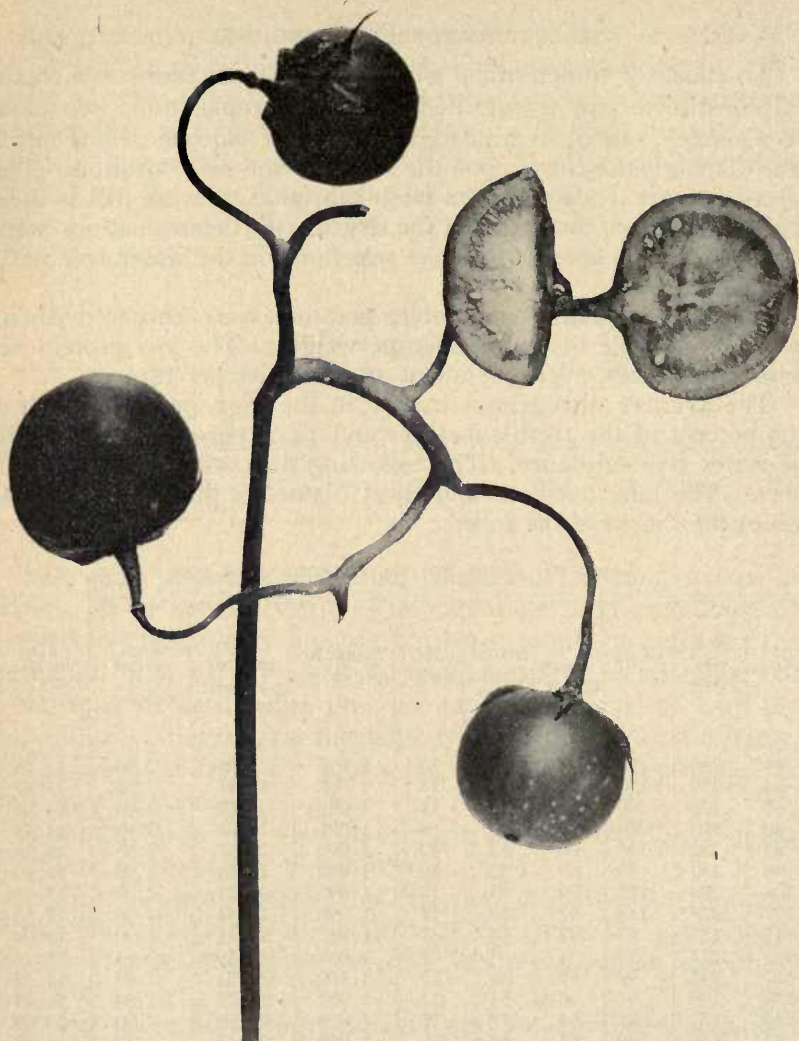


FIG. 10. POTATO FRUIT. NATURAL SIZE.

The plants in the two plots were up about the same time, but owing to the wet season and late planting on undrained land, were not vigorous. They were cultivated three times and sprayed twice with Paris green. Tip burn and Paris green injury combined to kill the plants very early. All plants on the two plots died at practically the same time.

Each potato planted produced from six to twenty tubers, but these were quite small, few being of marketable size. The tubers from the low protein plot were somewhat larger than those from the high protein plot.

Composite samples from the progeny of each tuber were made, and total nitrogen and moisture determined, as shown in the following tables:

TABLE 17. LOW PROTEIN SELECTIONS IN 1902

No.	Wt. g.	Long diam.	Me- dium diam.	Short diam.	No. Eyes.	Specific Gravity.	Dry Matter, percent.	Protein fr. b. percent.	Protein dry b. percent.
3	168	86	61	49	14	1.099	22.48	1.91	8.50
6	234	113	65	52	19	1.092	20.04	1.93	9.64
23	256	107	68	53	16	1.087	18.13	1.64	9.03
51	248	104	61	57	22	1.091	20.17	1.79	8.86
59	244	101	71	52	11	1.098	24.37	1.65	6.77
65	220	105	70	55	20	1.102	26.06	1.72	6.63
69	229	105	65	55	15	1.091	23.50	1.73	7.39
85	199	105	74	53	12	1.081	16.35	1.81	11.11
102	243	100	71	56	13	1.084	17.54	1.87	10.66
123	221	99	66	53	15	1.096	21.45	1.56	7.28
140	198	110	63	46	17	1.103	23.15	1.64	7.08
158	229	104	70	56	17	1.089	19.10	1.70	8.91
168	170	91	62	47	10	1.089	19.86	1.93	9.72
173	272	99	73	60	14	1.083	19.73	1.94	9.83
179	218	95	67	58	10	1.089	19.65	1.93	9.81
Aver.	223				14.9	1.092	22.10	1.78	8.75

TABLE 18. HIGH PROTEIN PLOT (CROP OF 1902)
(Weights, extremes 5 g. and 150 g., average 38 g.)

Row No.	From potato No.	Dry matter percent.	Nitrogenous matter, fr. b.	Nitrogenous matter, dry b.
1	44	13.55	2.48	18.48
2	63	13.56	2.51	18.46
3	68	10.50	1.24	11.83
4	80	11.50	1.39	12.11
*5	82	5.43	1.04	19.04
*6	99	6.33	1.18	18.59
7	104	14.54	2.17	14.96
8	107	10.75	1.28	11.96
9	111	8.00	1.58	19.81
*10	113	7.25	1.65	22.81
*11	117	7.00	1.66	23.74
12	129	14.57	1.79	12.29
13	137	13.92	2.00	14.35
14	147	13.00	2.25	17.33
15	166	14.83	2.26	15.26
General average		10.98	1.765	16.73
Average after rejection		13.07	1.937	14.70

*Very small, rejected.

TABLE 19. LOW PROTEIN PLOT (CROP OF 1902)
(Weights, extremes 10 g. and 180 g., average 68 g.)

Row No.	From potato No.	Dry matter percent.	Nitrogenous matter, fr. b.	Nitrogenous matter, dry b.
1	3	21.20	1.94	9.16
2	6	16.42	2.32	14.16
3	23	16.33	2.10	12.86
*4	51	7.50	1.25	16.68
5	59	11.15	1.66	14.93
*6	65	8.26	1.24	15.02
7	69	15.42	2.31	14.96
*8	85	8.28	1.16	14.00
9	102	15.33	2.18	14.27
10	123	16.02	1.92	12.00
11	140	14.55	1.49	10.20
12	158	14.50	2.02	13.95
*13	168	12.50	1.12	8.94
14	173	17.23	2.23	12.95
15	179	16.16	2.06	12.75
General average		14.056	1.80	13.12
Average after rejection		15.56	1.945	12.59

*Very small, rejected.

The general averages here, after rejecting the results from such hills as were far below marketable size indicate that there is no definite response to selection for high or low protein. It is true that the average of nitrogenous matter when calculated to the water free basis is 2.11 percent higher in the crop from the high nitrogen selections than in the crop from the low nitrogen selections. This, however, is wholly due to the difference in the average contents of dry matter, for the nitrogenous matter when calculated to the fresh substance, are practically the same.

There is an indication that the low protein potatoes are quicker to mature, for in the same growing period they had elaborated about twice as much fresh material, which contained 2.5 percent more dry matter than the high protein potatoes.

The poor development of the potatoes this season necessitated a return to other seed for the continuation of the experiment. This reduces the value the results of the second might have, as it was the intention to continue selecting from the same stock, with the hope of testing a possible cumulative effect of selection.

SELECTIONS FOR PLANTING, 1903

The experiment was continued in 1903, with the variety Early Ohio, which was considered to give better yields on Illinois soil. Unfortunately, the seed tubers which were obtained had been grown in southern Illinois on soil of an entirely different type from that upon which they were to be planted in the experiment, and there is no means of knowing whether the stock was adapted to the latter type.

These potatoes were of different type from those used in 1902, the Early Ohio being oblong-cylindrical. The average weight was smaller and the cooking quality poorer than those of the previous year. They were slightly infected with scab, but were fairly typical of the variety.

Two hundred nineteen individual tubers were analyzed in the same manner as those of the year before, with the result that fully as great variation in individuals was found in this variety.

Comparing the two varieties used (1902 and 1903), which of course is not strictly fair, owing to their being the product of different soils and seasons, it is seen that the higher average dry matter is shown in the round-flat variety, which is in accord with Fischer's theory.

The dry matter fluctuations were from 10.55 percent to 30.96 percent, with an average of 16.15 percent and a mode between 16.0 percent and 17.0 percent.

TABLE 20. VARIATIONS IN DRY MATTER. (CROP OF 1902, EARLY OHIO)

Dry matter, percent.....	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21
Frequencies....	4	5	7	20	19	44	54	27	24	13	3

The average nitrogenous matters, calculated to fresh basis is 2.43 percent, and calculated to water free basis is 15.21 percent. The variations in total nitrogenous matter are shown in the following table:

TABLE 21. VARIATIONS IN TOTAL NITROGENOUS MATTER. (CROP OF 1902, EARLY OHIO. DRY BASIS)

Nitrogenous matter, percent	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18
Frequencies....	1	1	0	1	7	14	39	40	46	27	11
Nitrogenous matter, percent	18-19	19-20	20-21	21-22	22-23	23-24	24-25	25-26	26-27	27-28	
Frequencies....	12	8	2	0	0	0	0	1	0	1	

The mode of nitrogenous matter is here between 15 percent and 16 percent. This is an amount of nitrogenous matter not to be despised. If the nitrogenous matter could be raised in the same proportion, when by cultivation under better conditions, a higher dry matter is obtained, there would be a food containing at least as much actual proteid nitrogen as many varieties of maize. It is highly probable that the two extreme high variations should be disregarded as errors, although potato No. 13 with a content of nitrogenous matter of 27.46 percent, weighed only 87 grams, which might account for rather high nitrogen content. The other tubers varied in weight from 150 to 300 grams.

Twenty tubers were selected for the high protein plot and fifteen for the low protein plot, selecting on the fresh basis, as before. The analyses of the individuals selected for planting are shown in Tables 22 and 23.

TABLE 22. HIGH PROTEIN SELECTIONS. 1903

Planted in row No.	Wt. Nit. matter fresh basis.	Dry matter, percent.	Nit. matter, dry basis.	Sp. gr.
1	2.78	14.28	19.42	1.063
2	3.12	15.53	20.01	1.058
3	2.93	10.66	27.46	1.092
4	3.03	15.10	20.04	1.060
5	2.78	14.93	18.60	1.059
6	2.78	15.35	18.10	1.061
7	2.80	10.74	25.91	1.062
8	2.92	16.74	17.42	1.059
9	2.90	18.85	15.36	1.064
10	2.80	15.66	17.85	1.056
11	2.79	17.60	15.81	1.062
12	2.77	15.34	18.06	1.062
13	2.83	18.96	14.91	1.069
14	2.81	16.99	16.53	1.069
15	2.86	17.99	16.39	1.067
16	2.93	19.62	14.93	1.074
17	2.83	17.36	16.31	1.063
18	2.85	18.94	15.04	1.066
19	2.77	16.18	17.10	1.066
20	2.77	17.49	15.85	1.060
General av.	2.85	16.215	18.055	1.064

TABLE 23. LOW PROTEIN SELECTIONS. 1903

Planted in row. No.	Wt. Nit. matter fresh basis.	Dry matter percent.	Nit. matter dry basis.	Sp. gr.
1	1.97	13.37	14.71	1.054
2	2.01	11.30	17.74	1.037
3	1.88	13.08	14.40	1.038
4	2.02	14.03	14.32	1.026
5	1.46	10.77	13.56	1.040
6	1.68	11.17	15.01	1.034
7	1.96	12.62	15.55	1.044
8	1.72	12.22	14.09	1.045
9	1.80	11.86	15.16	1.045
10	1.97	13.26	14.81	1.050
11	1.60	12.93	12.39	1.045
12	1.38	19.30	7.14	1.034
13	1.98	16.81	11.78	1.059
14	1.68	19.99	8.39	1.032
15	1.65	14.30	11.53	1.043
General av.	1.78	13.80	13.37	1.0417

There was a noticeable difference this year in the contents of dry matter of the two selections. The tubers planted in the high protein plot average 2.42 percent higher than those planted in the low protein plot. This reduces the average difference in content of nitrogenous matter between the tubers of the two classes, but there is still a difference of 4.69 percent, when calculated to the water free basis. This matter is of interest because it definitely shows that in mature tubers, a high percentage of nitrogenous matter is not correlated with a low dry matter content. This is additional evidence that potatoes of good quality, other things being equal, may be high in nitrogen. The average weight of the selections for the low protein plot was nine grams higher than those for the high protein plot.

The tubers were quartered and were planted in the same manner as in the year before, but on slightly better soil. The planting was done May 18, 1903, and the potatoes were up June second. Every cutting grew, but the growth was not luxuriant. It is thought that the seed may have been injured by the formalin treatment for scab. The plots were given ordinary farm cultivation, and were sprayed three times with Paris green and once with Bordeaux mixture.

The plants in both plots succumbed to tip burn and Paris green injury about the same time. The crop was larger than that of the year before, but not nearly all of the tubers were of marketable size. The potatoes were of different degrees of immaturity, but were sufficiently mature to make a fair comparison. Seventy-five percent by weight of the crop from the high protein plot averaged 75

grams in weight, while seventy-five percent by weight of the crop from the low protein plot averaged 70 grams in weight. The analyses of composite samples are given in the following tables:

TABLE 24. HIGH PROTEIN PLOT. (CROP OF 1903)

Row No.	Dry matter, percent.	Nit. matter, fresh basis.	Nit. matter, dry basis.
1	17.01	1.88	11.08
2	18.04	1.72	9.57
3	19.32	1.98	10.24
4	17.65	2.04	11.57
5	15.50	1.88	12.13
6	17.58	2.00	11.35
7	17.19	1.90	11.04
8	17.75	2.32	13.08
9	13.48	1.97	14.63
10	13.68	1.62	11.84
11	15.44	1.50	9.75
12	16.23	1.62	9.98
13	14.53	1.44	9.95
14	16.11	1.87	11.62
15	15.02	1.75	11.67
16	15.84	1.71	10.78
17	14.02	1.51	10.82
18	15.98	1.39	8.71
19	14.31	1.28	8.96
20	13.83	1.27	9.16
Gen. ave...	15.93	1.73	10.90

TABLE 25. LOW PROTEIN PLOT. (CROP OF 1903.)

Row No.	Dry matter, percent.	Nit. matter, fresh basis.	Nit. matter, dry basis.
1	14.80	1.23	8.32
2	14.11	1.20	8.47
3	15.93	1.44	9.06
4	15.72	1.30	8.31
5	15.61	1.36	8.76
6	14.68	1.58	10.76
7	13.87	1.28	9.27
8	16.41	1.36	8.26
9	15.94	1.46	9.15
10	14.92	1.37	9.23
11	14.98	1.30	8.69
12	14.38	1.76	12.28
13	13.91	1.31	9.42
14	15.28	1.52	9.96
15	16.21	15.1	9.32
Gen. ave...	15.12	1.40	9.29

No very definite conclusions can be drawn from this one season's work, yet in comparing a possible inheritance of variations, the difference of .81 percent in dry matter is noteworthy. It should be remembered that the low protein potatoes were larger and from them should have ordinarily been expected the higher dry matter. The difference in total nitrogenous matter, in favor of the high protein plot was 0.33 percent upon the fresh sample and 1.61 percent upon the dried sample. The regression of each plot toward the same type in percentages of dry matter and nitrogenous material is great but no more than would have been expected from seed propagated selections.

Note.—This experiment is being continued on a somewhat different plan. A variety of potatoes has been produced, coming from a single tuber of a seedling of four years ago. With these tubers two plots are being carried on, one for high and one for low nitrogen. It is expected by thus having a check upon the effects of soil, and having to deal with an accurately estimated character, to be able definitely to demonstrate whether there is inheritance of asexual fluctuations.

GENERAL STATEMENTS

The improvement of our present varieties of potatoes in yielding power, and the enhancing of particularly valuable characters through breeding and selection have been shown in the foregoing pages to be broad and many sided questions. They are beset with difficulties such as are attendant on the improvement of no other important field crop. But if the questions are difficult, some of them are far reaching in their bearing and the subject seems alike worthy the attention of the biologist seeking experimental evidence concerning the meaning of sex and the inheritance of fluctuating characters; and the practical breeder whose relative success in the production of new varieties is measured by dollars and cents.

The use of other tuber bearing species of *Solanum* as a starting point for new varieties has not yet produced anything of value. Hope is still entertained that *S. Commersonii* crossed, or hybridized, with *S. tuberosum* will finally produce something that is disease resistant and satisfactory in other respects. The present evidence, however, seems to point towards some correlation of quality with susceptibility to disease, so that definite knowledge of the physiological meaning of fungus resistance is most probably the key to the door we must enter.

The fairly extensive recorded history of *S. tuberosum* for three hundred years is interesting to the student of changes under domestication, in that the changes which have taken place in the plant have been almost entirely in the selected part, the tuber. Even the change in the tubers seems to be largely a matter of lesser numbers and larger size per plant. The minor distinctions that have separated modern varieties have been in the main those of shape and color. Slight differences, provided the variety is a fairly high yielder, have been the cause of a large number of names, but in the United States, at least, the productions of scientific breeders comparatively few in number, furnish practically the entire crop of the country.

Methods of hybridizing the potato are comparatively simple, but the variation of the varieties in their ability to furnish viable pollen has been a source of disappointment with a great many varieties possessing other particularly good characters. A problem here is to find means of stimulating the production of pollen in these varieties. This matter is also of special theoretical interest in its bearing on the production of sex.

The method of propagating the potato has seriously increased the number of errors in making comparative field tests during the establishment of varieties. The fact that the seedlings must be grown several years in the comparison test before making definite selections, makes care in this respect still more important. The discovery of characters in the young plant which are correlated with characters in the tuber would be of great advantage in shortening the time of their comparison before final rejection of the unfit. Some work has already been done in this direction.

Possible methods of improvement are three:

1. The crossing of desirable plants and raising of many seedlings under controlled conditions.
2. Selections of the most desirable fluctuations among the plants and tubers of a variety.
3. Selection of discontinuous variations, and a study of ways of causing them, a possible example being the so-called graft-hybrid.

That advance is possible by the first method is admitted from the results of its use by the best breeders. More data as to the best details for work in use of this method, however, are very desirable. Whether results can be obtained by the second method has not been definitely proved. The data here shown which do point to the affirmative, are not conclusive. Isolated cases of improvement might reasonably be explained as due to mutations.

The hypothesis of degeneration seems to have little ground either in theory or in practice. Disease control is here of paramount importance.

Table quality, according to the American standard, depends primarily upon homogenous structure of the tuber, when mature tubers of a fair percentage dry matter are compared. This condition is to a large extent a varietal character and as such is probably capable of improvement. That this can be done by selection of tubers within a variety has not yet been definitely determined, but is improbable.

Tubers with a total content of nitrogenous matter beyond the average for maize (calculated to dry basis) have been found. It has been shown that a high nitrogen content, at least within the limit found, is not through any law of composition, opposed to our conception of quality.

That varieties can be produced with a much higher food value because of their higher nitrogen content, by selection of seedlings from their chemical analysis is not to be doubted.

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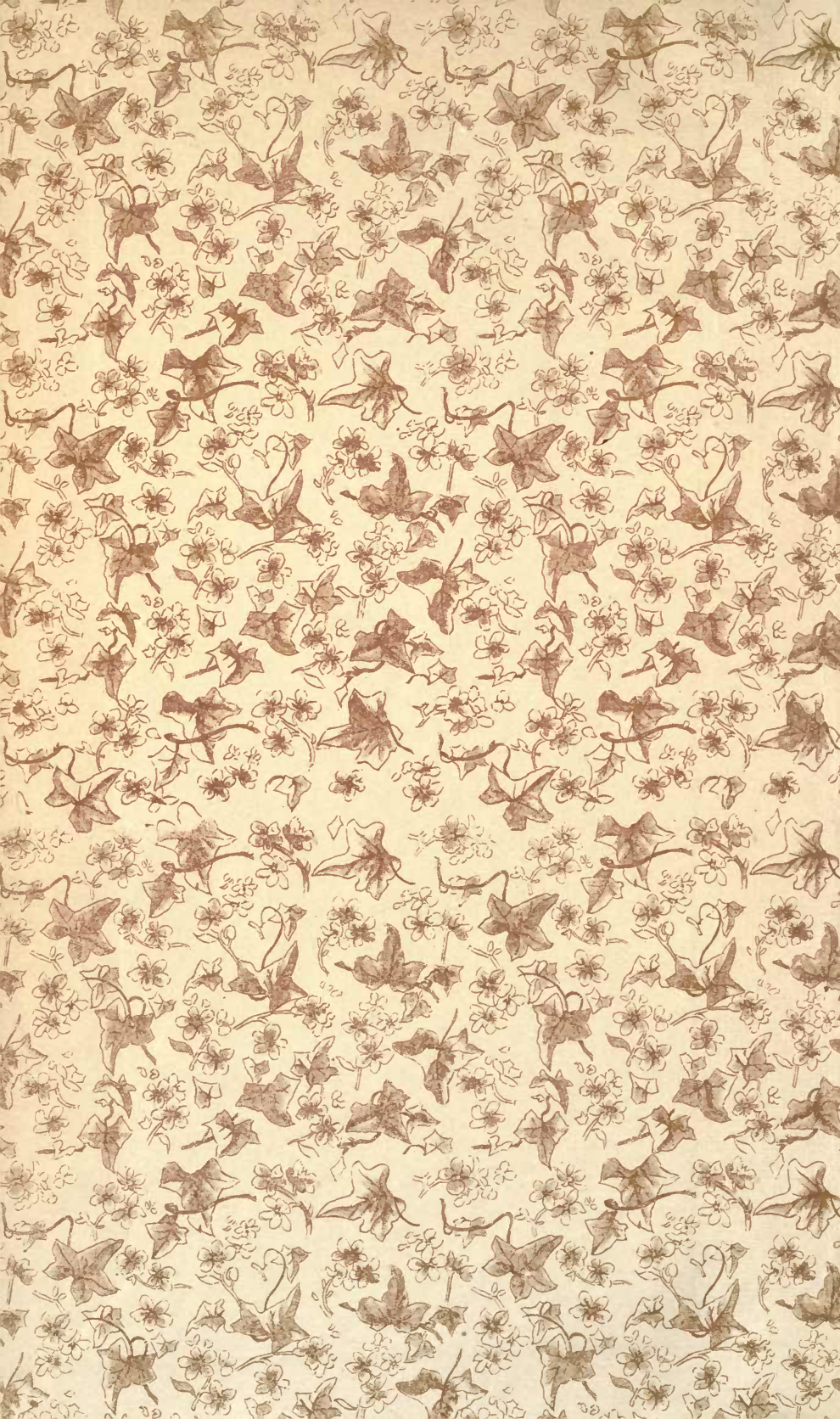
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